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4 **Title**

5 An Apparatus and Method And Techniques for Measuring and Correlating
6 Characteristics of Fruit With Visible/Near Infra-Red Spectrum

7 **Continuation In Part Application**

8 This is a Continuation In Part Application copending from the nonprovisional
9 parent application 09/524,329 entitled AN APPARATUS AND METHOD FOR
10 MEASURING AND CORRELATING CHARACTERISTICS OF FRUIT WITH
11 VISIBLE/NEAR INFRA-RED SPECTRUM to Ozanich as filed March 13, 2000.
12 The applicant requests prosecution pursuant to 37 C.F.R. 1.53(b) and 1.78 and 35
13 U.S.C. 120. New matter herein is added, for examination convenience, commencing
14 with page 56 which follows the last line of the Detailed Description of the original
15 application and precedes the claims. ~~Drawings are added commencing with Fig. 9~~
16 ~~and including Fig. 9, 10, 10A, 11, 12, 13, 14, 14A, 15 and 15A. Claim 9 pending in~~
17 ~~the parent has been preliminarily amended prior to the first office action. Claim 9A~~
18 ~~has been added as an amendment preliminary to the first office action. Claims have~~
19 ~~been added, in this Continuation-In-Part Application commencing with claim 22.~~

20 **Field of the Invention**

21 The present disclosure relates generally to the use of the combined visible and
22 near infra red spectrum in an apparatus and method for measuring physical
23 parameters, e.g., firmness, density and internal and external disorders, and chemical
24 parameters, e.g., molecules containing O-H, N-H and C-H chemical bonds, in fruit
25 and correlating the resulting measurements with fruit quality and maturity
26 characteristics, including Brix, acidity, density, pH, firmness, color and internal and
27 external defects to forecast consumer preferences including taste preferences and
28 appearance, as well as harvest, storage and shipping variables. With the present
29 apparatus and method, the interior of a sample, e.g., fruit including apples, is

1 illuminated and the spectrum of absorbed and scattered light from the sample is
2 detected and measured. Prediction, calibration and classification algorithms are
3 determined for the category of sample permitting correlation between the spectrum of
4 absorbed and scattered light and sample characteristics, e.g., fruit quality and
5 maturity characteristics.

6 Background of the Invention

7 The embodiments disclosed herein has a focus on combined visible and near-
8 infrared (NIR) spectroscopy and its modes of use, major issues in the application of
9 NIR to the measurement of O-H, N-H and C-H containing molecules that are
10 indicators of sample quality including fruit quality and in particular tree fruit quality.

11 **Near-Infrared Spectroscopy Background:** Near-infrared spectroscopy has
12 been used since the 1970's for the compositional analysis of low moisture food
13 products. However, only in the last 10-15 years has NIR been successfully applied to
14 the analysis of high moisture products such as fruit. NIR is a form of vibrational
15 spectroscopy that is particularly sensitive to the presence of molecules containing C-
16 H (carbon-hydrogen), O-H (oxygen-hydrogen), and N-H (nitrogen-hydrogen) groups.
17 Therefore, constituents such as sugars and starch (C-H), moisture, alcohols and acids
18 (O-H), and protein (N-H) can be quantified in liquids, solids and slurries. In addition,
19 the analysis of gases (e.g., water vapor, ammonia) is possible. NIR is not a trace
20 analysis technique and it is generally used for measuring components that are present
21 at concentrations greater than 0.1%.

22 **Short-Wavelength NIR vs. Long-Wavelength NIR:** NIR has traditionally
23 been carried out in the 1100-2500 nm region of the electromagnetic spectrum.
24 However, the wavelength region of ~700-1100 nm (short wavelength-NIR or SW-
25 NIR) has been gaining increased attention. The SW-NIR region offers numerous
26 advantages for on-line and *in-situ* bulk constituent analysis. This portion of the NIR
27 is accessible to low-cost, high performance silicon detectors and fiber optics. In
28 addition, high intensity laser diodes and low-cost light emitting diodes are becoming
29 increasingly available at a variety of NIR wavelength outputs.

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1 The relatively low extinction (light absorption) coefficients in the SW-NIR
2 region yields linear absorbance with analyte concentration and permits long,
3 convenient pathlengths to be used. The depth of penetration of SW-NIR is also much
4 greater than that of the longer wavelength NIR, permitting a more adequate sampling
5 of the "bulk" material. This is of particular importance when the sample to be
6 analyzed is heterogeneous such as fruit.

7 **Diffuse Reflectance Sampling vs. Transmission Sampling:** Traditional
8 NIR analysis has used diffuse reflectance sampling. This mode of sampling is
9 convenient for samples that are highly light scattering or samples for which there is
10 no physical ability to employ transmission spectroscopy. Diffusely reflected light is
11 light that has entered a sample, undergone multiple scattering events, and emerged
12 from the surface in random directions. A portion of light that enters the sample is
13 also absorbed. The depth of penetration of the light is highly dependent on the
14 sample characteristics and is often affected by the size of particles in the sample and
15 the sample density. Furthermore, diffuse reflectance is biased to the surface of a
16 sample and may not provide representative data for large heterogeneous samples such
17 as apples.

18 While transmission sampling is typically used for the analysis of clear
19 solutions, it also can be used for interrogating solid samples. A transmission
20 measurement is usually performed with the detector directly opposite the light source
21 (i.e., at 180 degrees) and with the sample in the center. Alternately the detector can
22 be placed closer to the light source (at angles less than 180 degrees), which is often
23 necessary to provide a more easily detected level of light. Because of the long sample
24 pathlengths and highly light scattering nature of most tree fruit, transmission
25 measurements can only be performed in the SW-NIR wavelength region, unless
26 special procedures are employed to improve signal to noise.

27 **NIR Calibration:** NIR analysis is largely an empirical method; the spectral
28 lines are difficult to assign, and the spectroscopy is frequently carried out on highly
29 light scattering samples where adherence to Beer's Law is not expected.

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1 Accordingly, statistical calibration techniques are often used to determine if there is a
2 relationship between analyte concentration (or sample property) and instrument
3 response. To uncover this relationship requires a representative set of "training" or
4 calibration samples. These samples must span the complete range of chemical and
5 physical properties of all future samples to be seen by the instrument.

6 Calibration begins by acquiring a spectrum of each of the samples.
7 Constituent values for all of the analytes of interest are then obtained using the best
8 reference method available with regards to accuracy and precision. It is important to
9 note that a quantitative spectral method developed using statistical correlation
10 techniques can perform no better than the reference method.

11 After the data has been acquired, computer models employing statistical
12 calibration techniques are developed that relate the NIR spectra to the measured
13 constituent values or properties. These calibration models can be expanded and must
14 be periodically updated and verified using conventional testing procedures.

15 Factors affecting calibration include fruit type and variety, seasonal and
16 geographical differences, and whether the fruit is fresh or has been in cold or other
17 storage. Calibration variables include the particular properties or analytes to be
18 measured and the concentration or level of the properties. Intercorrelations (co-
19 linearity) should be minimized in calibration samples so as not to lead to false
20 interpretation of a models predictive ability. Co-linearity occurs when the
21 concentrations of two components are correlated, e.g., an inverse correlation exists
22 when one component is high, the other is always low or vice versa.

23 Application of NIR to Tree Fruit and Existing On-Line NIR

24 **Instrumentation:** A growing body of research exists for NIR analysis of tree fruit.
25 NIR has been used for the measurement of fruit juice, flesh, and whole fruit. In juice,
26 the individual sugars (sucrose, fructose, glucose) and total acidity can be quantified
27 with high correlation (>0.95) and acceptable error. Individual sugars can not be
28 readily measured in whole fruit. Brix is the most successfully measured NIR
29 parameter in whole fruit and can generally be achieved with an error of ± 0.5 -1.0 Brix.

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1 More tentative recent research results indicate firmness and acidity measurement in
2 whole fruit also may be possible.

3 Only in Japan has the large-scale deployment of on-line NIR for fruit sorting
4 occurred. These instruments require manual placement/orientation of the fruit prior
5 to measurement and early versions were limited to a measurement rate of three
6 samples per second. The Japanese NIR instruments are also limited to a single lane
7 of fruit and appear to be difficult to adapt to multi-lane sorting equipment used in the
8 United States of America. While earlier Japanese NIR instruments employed
9 reflectance sampling, more recent instruments use transmission sampling.

10 In Koashi et al., U.S. Pat. No. 4,883,953, there is described a method and
11 apparatus for measuring sugar concentrations in liquids. Measurements are made at
12 two different depths using weak and strong infrared radiation. The level of sugar at
13 depths between these two depths can then be measured. The method and apparatus
14 utilizes wavelength bands of 950-1,150 nm, 1,150-1,300 nm, and 1,300-1,450 nm.

15 U.S. Pat. No. 5,089,701, to Dull et al., uses near infrared (NIR) radiation in
16 the wavelength range of 800-1,050 nm to demonstrate measurement of soluble solids
17 in Honeydew melons. An eight-centimeter or greater distance between the light
18 delivery location to the fruit and the light collection location was found to be
19 necessary to accurately predict soluble solids because of the thick rind.

20 Iwamoto et al., U.S. Pat. No. 5,324,945, also use NIR radiation to predict
21 sugar content of mandarin oranges. Iwamoto utilizes a transmission measurement
22 arrangement whereby the light traverses through the entire sample of fruit and is
23 detected at 180 degrees relative to the light input angle. Moderately thick-skinned
24 fruit (mandarin oranges) were used to demonstrate the method, which relies on a fruit
25 diameter correction by normalizing (dividing) the spectra at 844 nm, where,
26 according to the disclosed data, correlation with the sugar content is lowest. NIR
27 wavelengths in the range of 914-919 nm were found to have the highest correlation
28 with sugar content. Second, third and fourth wavelengths that were added to the
29 multiple regression analysis equation used to correlate the NIR spectra with sugar
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1 content were 769-770 nm, 745 nm, and 785-786 nm.

2 In U.S. Pat. No. 5,708,271, Ito et al. demonstrates a sugar content measuring
3 apparatus that utilizes three different NIR wavelengths in the range from 860-960 nm.
4 The angle between light delivery and collection was varied between 0 and 180
5 degrees and it was concluded that the low NIR radiation levels that must be detected
6 when a photo-detector is placed at 180 degrees relative to the radiation source are not
7 desirable because of the more complicated procedures and equipment that are
8 required. A correlation of NIR absorbance with sugar content of muskmelons and
9 watermelons was found when an intermediate angle, which gave greater NIR
10 radiation intensity, was detected. No size correction was necessary with this
11 approach.

12 U.S. Pat. No. 4,883,953 to Koashi et al. uses comparatively long wavelengths
13 of NIR radiation (i.e., >950 nm), while in U.S. Pat. Nos. 5,089,701 to Dull, and
14 5,708,271 to Ito, wavelengths of NIR radiation used are greater than 800 nm and 860
15 nm, respectively. In U.S. Pat. No. 5,324,945 to Iwamoto, the wavelengths of NIR
16 radiation with the highest correlation to sugar content of mandarins were 914 nm or
17 919 nm, when the fruit were measured on the equatorial or stem portion, respectively.
18 All of these methods use near-infrared wavelengths of light to correlate with sugar
19 content of whole fruit. No other quality parameters are measured by these
20 techniques.

21 The four disclosed patents are similar to the apparatus and method described
22 here in that the present disclosure also measures sugar content. Two of the patents
23 (Pat. No. 5,089,701 and 5,324,945) NIR wavelengths less than 850 nm) Pat. No.
24 5,089,701 discloses the operation of the invention within the range of "from about
25 800 nanometers to about 1050 nanometers." U.S. Pat. No. 5,324,945 lists 914 nm or
26 919 nm as the primary analytical wavelength correlated with whole fruit sugar
27 content; multiple linear regression was used to add successive wavelengths to the
28 model as follows: 769-770 nm (2nd wavelength added), 745 nm (3rd wavelength
29 added), and 785-786 nm (4th wavelength added). In Pat. No. 5,089,701, addition of
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1 the fourth wavelength to the model only reduced the standard error of prediction
2 (SEP) by 0.1-0.2 Brix, which is approaching or less than the error limits of the
3 refractometer used to determine the reference ("true") Brix values.

4 Other similarities between the method and apparatus described herein with the
5 four patents listed above include the use of multivariate statistical analysis to
6 establish correlation of the near-infrared spectral data with sugar content of whole
7 fruit. Most also use data processing techniques such as second derivative
8 transformation and some type of spectral normalization. All of these methods for
9 relating NIR spectra to chemical or physical properties are well known to those
10 practiced in the art of NIR spectroscopy.

11 The foregoing patents and printed publications are provided herewith in an
12 Information Disclosure Statement in accordance with 37 CFR 1.97.

13 Summary of the Invention

14 Research groups around the world continue to explore the applications of near
15 infrared spectroscopy to tree fruit. The apparatus and process disclosed herein is of
16 the nondestructive determination or prediction of O-H, N-H and C-H containing
17 molecules that are indicators of sample qualities, including fruit such as apples,
18 cherries, oranges, grapes, potatoes, cereals, and other such samples, using near-
19 infrared spectroscopy. Prior art has utilized spectrum from 745nm and above. This
20 disclosure is of 1) the utilization of the spectrum from 250 nm to 1150 nm for
21 measurement or prediction of one or more parameters, e.g., Brix, firmness, acidity,
22 density, pH, color and external and internal defects and disorders including, for
23 example, surface and subsurface bruises, scarring, sun scald, punctures, watercore,
24 internal browning, in samples including fruit; 2) an apparatus and method of
25 illuminating the interior of a sample and detecting emitted light from samples
26 exposed to the above spectrum in at least one spectrum range and, in the preferred
27 embodiment, in at least two spectrum ranges of 250 to 499nm and 500nm to 1150nm;
28 3) the use of the chlorophyll absorption band, peaking at 680nm, in combination with
29 the spectrum from 700nm and above to predict one or more of the above parameters;

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1 4) the use of the visible pigment region, including xanthophyll, from approximately
2 250nm to 499nm and anthocyanin from approximately 500 to 550nm, in combination
3 with the chlorophyl band and the spectrum from 700nm and above to predict the all
4 of the above parameters.

5 Prior art has only examined spectrum from fruit for the prediction of Brix.
6 This disclosure is of the examination of a greater spectrum using the combined
7 visible and near infrared wavelength regions for the prediction of the above stated
8 characteristics. The apparatus and method disclosed eliminates the problem of
9 saturation of light spectrum detectors within particular spectrum regions while
10 gaining data within other regions in the examination, in particular, of fruit. That is,
11 spectrometers with CCD (charge coupled device) array or PDA (photodiode array)
12 detectors will detect light within the 250 to 1150nm region, but when detecting
13 spectrum out of fruit will saturate in regions, e.g., 700 to 925nm, or the signal to
14 noise (S/N) ratio will be unsatisfactory and not useful for quantitation in other
15 regions, e.g., 250 to 699nm and greater than 925nm, thus precluding the gaining of
16 additional information regarding the parameters above stated. Thus disclosed herein
17 is an apparatus and method permitting 1) the automated measurement of multiple
18 spectra with a single pass or single measurement activity by detecting more than one
19 spectrum range during a single pass or single measurement activity, 2) combining the
20 more than one spectrum range detected, 3) comparing the combined spectrum with a
21 stored calibration algorithm to 4) predicting the parameters above stated.

22 In each instance in the method and apparatus disclosed herein there will be a
23 dual or plural spectrum acquisition from a sample from different spectrum regions.
24 This is accomplished by 1) serially acquiring data from different spectrum regions
25 using different light source intensities or different detector/spectrometer exposure
26 times using a single spectrometer; 2) acquiring data in parallel with multiple
27 spectrometers using different light intensities, e.g., by varying the voltage input to a
28 lamp, or different exposure times to the spectrometers; however, different exposure
29 times leads to sampling errors particularly where a sample is moving, e.g., in a
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1 processing line, due to viewing different regions on a sample; and 3) with multiple
2 spectrometers using the same exposure time, constant lamp intensity with dual or a
3 plurality of light detectors including neutral density filtered light detectors (where
4 filtered light detectors giving the same effect as using a shorter exposure time). This
5 approach provides dual or plural spectra with good signal to noise ratio for all
6 wavelengths intensities using a single light source intensity and the same exposure
7 time on all spectrometer detectors. This approach uses at least one filtered light
8 detector using filtered input 82 to the spectrometer 170 rather than different exposure
9 times. A filter can be any material that absorbs light with equal strength over the
10 range of wavelengths used by the spectrometer including but not limited to neutral
11 density filters, Spectralon, Teflon, opal coated glass, screen. The dual intensity
12 approach using two different lamp voltages proves problematic because the high and
13 low intensity spectra are not easily combined together due to slope differences in the
14 spectra. The dual exposure approach yields excellent combined spectra, which are
15 necessary for firmness and other characteristic prediction and also improves Brix
16 prediction accuracy.

17 Measurements are disclosed, with the apparatus and process of this disclosure,
18 which are made simultaneously in multiple sample types, e.g., where samples are
19 apples, measurement is independent of a particular apple cultivar, using a single
20 calibration equation with errors of $\pm 1-2$ lb. and $\pm 0.5-1.0$ Brix. This disclosure
21 pertains to laboratory, portable and on-line NIR analyzers for the simultaneous
22 measurement of multiple quality parameters of samples including fruit. Depending
23 on the application or particular characteristic sought to be predicted or measured, a
24 variety of calibration models may be used, from universal to highly specific, e.g., the
25 calibration can be specific to a variety, different geographical location, stored v. fresh
26 fruit and other calibrations.

27 Disclosed here is the greater role NIR technology will play as a tool for
28 grading sample qualities including fruit quality. The unique ability of NIR statistical
29 calibration techniques to extract non-chemical "properties" provides a technique for
30

1 development of a general NIR "quality index" for tree fruit. This general "quality
2 index" combines all of the information that could be extracted from the NIR spectra
3 and includes information about Brix, acidity, firmness, density, pH, color and
4 external and internal disorders and defects.

5 The near-infrared wavelength region below 745 nm has not been explored by
6 prior investigations. Generally, the prior art design and or apparatus utilized was
7 such that longer wavelength regions provided adequate data. The prior art for
8 measuring sugar content in liquids and whole fruits using near-infrared spectroscopy
9 utilizes longer wavelengths of radiation. No prior art exists for measuring other
10 important quality parameters such as firmness, acidity, density and pH. No prior art
11 has correlated consumer taste preferences with the combined NIR determination of
12 multiple quality parameters such as sugar, acidity, pH, firmness, color, and internal
13 and external defects and disorders.

14 It will be shown in this patent that the wavelength region from 250-1150 nm
15 can be used to nondestructively measure not only sugar content (Brix) in various
16 whole fruit, but firmness, density, acidity, pH, color and internal and external defects
17 as well. For example, density of oranges is measured and is correlated to quality,
18 e.g., freeze damaged fruit and dry fruit typically have lower density than good quality
19 fruit and lower water content (i.e., greater dry matter content). NIR density
20 measurement can be used to remove poor quality fruit in a sorting/packing line or at
21 the supermarket. Information about color pigments and chlorophyll, related to
22 maturity and quality, are obtained from 250 to approximately 699 nm. From
23 approximately 700-1150 nm, the short wavelength NIR region, C-H, N-H, O-H
24 information is obtained. Combining the visible and NIR region gives more analytical
25 power to predict chemical, physical and consumer properties, particularly for fruit.
26 All of these parameters can be determined simultaneously from a combined
27 visible/NIR spectrum. Multiple parameters can be combined to arrive at a "Quality
28 Index" that is a better measure of maturity or quality than a single parameter.

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1 Absorption of light by whole fruit in the approximately 250-699 nm region is
2 dominated by pigments, including chlorophyll (a green pigment) which absorbs in the
3 approximately 600-699 nm region. Chlorophyll is composed of a number of
4 chlorophyll-protein complexes. Changes in these chlorophyll-protein complexes and
5 changes in other pigments, most notably anthocyanin (red pigment) and xanthophylls
6 (yellow pigments), are related to the maturation and ripening process. Chlorophyll
7 and pigments are important for determining firmness.

8 While the NIR wavelengths of 700-925 nm and longer have been readily
9 accessible to common near-infrared spectrometers, shorter wavelengths have not
10 typically been explored for the following reasons: 1) lead-salt and other detector
11 types, e.g., InGaAs, were not sensitive to shorter wavelengths; 2) light diffraction
12 gratings were blazed at longer wavelengths yielding poor efficiency at short
13 wavelengths; 3) light sources did not have enough energy output at shorter
14 wavelengths to overcome the strong light absorption and scattering of biological
15 (plant and animal) material in the visible region (250-699 nm).

16 Disclosed herein is an apparatus and method for measurement, with the
17 visible/near-infrared (VIS/NIR) spectroscopic technique for sugar content (also
18 known as Brix or soluble solids, which is inversely related to dry matter content),
19 firmness, acidity, density, pH, color and internal and external defects and disorders.
20 The apparatus and method is successful in measuring one or more such characteristic
21 in apples, grapes, oranges, potatoes and cherries. Demonstrated in this disclosure is
22 the ability to combine chemical and physical property data permitting the prediction
23 of consumer properties, such as taste, appearance and color; harvest variables, such as
24 time for harvest; and storage variables such as prediction of firmness retention and
25 time until spoilage.

26 Brief Description of the Drawings

27 The foregoing and other features and advantages of the present disclosure will
28 become more readily appreciated as the same become better understood by reference
29 to the following detailed description of the preferred embodiment and additional

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1 embodiments of the disclosure when taken in conjunction with the accompanying
2 drawings, wherein:
3 FIG. 1 is a top plan showing an embodiment of the disclosure illustrating a sample
4 holder having a securing or spring biasing article urging a holding article in contact
5 with a sample having a sample surface, a light detector having a light detector
6 securing or spring biasing article and light sources proximal the sample surface with
7 the light sources positioned in relation to the light sensor generally orthogonal to the
8 sample surface. An optional filter may be positioned between the light source and the
9 sample or between the sample and a spectrometer(s). The light sources may be
10 controlled by the CPU. The output from the light sensor becomes the input to a light
11 detector such as a CCD array within a spectrometer.

12
13 ~~FIG. 1 is a top plan of an embodiment of an apparatus for measuring and correlating~~
14 ~~characteristics of fruit with combined visible and near infrared spectrum showing an~~
15 ~~embodiment of the disclosure illustrating a sample holder having a securing or spring~~
16 ~~biasing article urging a holding article, shown here essentially as hemispherical, in~~
17 ~~contact with a sample having a sample surface, and preventing the sample from~~
18 ~~movement, a sample shown as an apple, a light detector having a light detector~~
19 ~~securing or spring biasing article placing or holding the light detector in contact with~~
20 ~~the sample surface, and light sources proximal the sample surface with the light~~
21 ~~sources positioned between 0 and 90 degrees, e.g., typically 45 degrees, in relation to~~
22 ~~the light sensor. The light source and light detector are positioned generally~~
23 ~~orthogonal to the sample surface. The light sources may be, for example,~~
24 ~~tungsten/halogen lamps. An optional filter or filters functioning as heat block,~~
25 ~~bandpass and or cutoff filters may be positioned between the light source and the~~
26 ~~sample or between the sample and a spectrometer(s). The light sources may, for~~
27 ~~example but without limitation, be 5W lamp sources from a spectrometer or one or~~
28 ~~more external light sources controlled by the CPU with power up to 1000 Watts~~
29 ~~each, but more typically 50 Watt, 75 Watt or 150 Watt. The output from the light~~
30

1 ~~sensor, shown here as a fiber-optic sensor, becomes the input to a light detector such~~
2 ~~as a CCD array within a spectrometer. The sample holder, light detector securing~~
3 ~~article and light sources with light source securing article are affixed to a plate or~~
4 ~~other fixture. Other fixtures or articles may be employed to secure or position a~~
5 ~~sample requiring only that the device or method used retain the sample in position~~
6 ~~relative to the light source and light detector during the period of measurement.~~

7

8 Fig. 1A is a side elevation section of Fig 1.

9

10 Fig. 1B is a side elevation section of Fig 1 with no sample additionally showing a
11 light source securing article.

12

13 Fig. 1C is a flow diagram demonstrating the method of this invention. The flow
14 diagram is schematically representative of all embodiments of this disclosure.

15

16 Fig. 1D is a flow diagram demonstrating the method and apparatus illustrating the
17 light source(s) which illuminate a sample, light collection channels 1...n (light
18 detector 1...n) of the spectra from a sample delivered as input to a spectra measuring
19 device, shown here as spectrometer 1...n. Spectrometer 1...n channels output 1...n are
20 converted from analog to digital and become, for each channel, input to a CPU. The
21 CPU is computer program controlled. The CPU output is also for each channel 1...n.

22

23 ~~Fig. 1D is a flow diagram demonstrating the method and apparatus illustrating the~~
24 ~~light source(s) which illuminate a sample, light collection channels 1...n (light~~
25 ~~detector 1...n) of the spectra from a sample delivered as input to a spectra measuring~~
26 ~~device, shown here as spectrometer 1...n. Spectrometer 1...n channels output 1...n are~~
27 ~~converted from analog to digital and become, for each channel, input to a CPU. The~~
28 ~~CPU is computer program controlled with each step, following the CPU in this flow~~
29 ~~diagram representative of a computer program controlled activity. The CPU output is~~

30

1 also for each channel 1...n where the steps of 1) calculating of absorbance spectra
2 occurs for each channel 1...n, 2) combining absorbance spectra into a single spectrum
3 encompassing the entire wavelength range detected from the sample by spectrometers
4 1...n, 3) mathematical preprocessing, e.g., smoothing or box-car smooth or calculate
5 derivatives, 4) comparing the preprocessed combined spectra with the stored
6 calibration spectrum for each characteristic, 1...x, for which the sample is examined;
7 5) sorting decisions are made based on the results of step 4) or with 6) further
8 combinations and comparisons of the results of quantification of each characteristic,
9 1...x, for which the sample is examined. Absorbance is calculated as follows: once
10 the dark spectrum, reference spectrum and sample spectrum are collected, they are
11 processed to compute the absorbance spectrum, which Beer's law indicates is
12 proportional to concentration. The dark spectrum, which may include
13 background/ambient light, is subtracted from both the sample spectrum and the
14 reference spectrum. The log base 10 of the reference spectrum divided by the sample
15 spectrum is then calculated. This is the absorbance spectrum. It is noted that dark
16 and reference can be collected periodically, i.e., they do not necessarily need to be
17 collected along with every sample spectrum. A stored dark and reference can be used
18 if light source and detector are stable and don't drift. Pre-processing uses techniques
19 known to those practiced in the art such as binning, smoothing, wavelength ratioing,
20 taking derivatives, spectral normalizing, wavelength subtracting, etc. Then the
21 processed absorbance spectrum will be compared with a stored calibration algorithm
22 to produce an output representative or predictive of one or more characteristics, e.g.,
23 firmness, Brix, pH, acidity, density, color, and internal and external defects or acidity,
24 of the sample 30.

25

26 Fig. 1E is a flow diagram demonstrating the method and apparatus illustrating the
27 light source(s) 120 as a broad band source which illuminates a sample 30; at least one
28 discrete wavelength filtered (bandpass) photodetectors 255 having filters 130 for light
29 collection channels 1...n from a sample 30. In this embodiment a light source 120

30

1 with lamp 123 is controlled by a CPU 172. The spectrum detected from the sample
2 surface 35 may be communicated by fiber optic fibers as light detectors 80 to the
3 photodetectors 255.

4
5 ~~Fig. 1E is a flow diagram demonstrating the method and apparatus illustrating the~~
6 ~~light source(s) as a broad band source, such as a tungsten halogen lamp, which~~
7 ~~illuminates a sample; at least one, but in the preferred embodiment a plurality, of~~
8 ~~discrete wavelength filtered (bandpass) photo detectors provide spectrum detection~~
9 ~~for light collection channels 1...n (photo detector 1...n) of the spectra from a sample.~~
10 ~~The management of the detected spectra is as described for Fig. 1D.~~

11 ~~Fig. 1F is a flow diagram demonstrating the method and apparatus illustrating the~~
12 ~~light source(s) provided by discrete wavelength light emitting diodes(LEDs) which~~
13 ~~may be sequentially fired or lighted to illuminate a sample; at least one broadband~~
14 ~~photo detector and, in an alternative embodiment a least one broadband photo~~
15 ~~detector for each LED, provide spectrum detection for light collection channels 1...n~~
16 ~~(photo detector 1...n) of the spectra from a sample. The management of the detected~~
17 ~~spectra is as described for Fig. 1D. Alternative light sources for this embodiment~~
18 ~~include but are not limited to tunable diode lasers, laser diodes and the use of a filter~~
19 ~~wheel between the light source and the sample or between the sample and~~
20 ~~photodetector.~~

21
22 Fig. 1F is a flow diagram demonstrating the method and apparatus illustrating the
23 light source(s) provided by at least one discrete wavelength light emitting diodes 257
24 to illuminate a sample 30; at least one broadband photodetector 255 and at least one
25 broadband photodetector 255 for each LED 257 for light collection channels 1...n
26 (photodetector 1...n) of the spectra from a sample.

27
28 Fig. 2 is a top plan depicting at least one light source, with a single light source
29 shown in this illustration, with optional filter and with at least one light detector, with

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1 a plurality of light detectors illustrated, proximal to the sample surface. This
2 depiction demonstrates an orientation of light detectors relative to the direction of
3 light cast on the sample surface with one light detector oriented at approximately 45
4 degrees to the direction of the light cast by the light source and a second light detector
5 oriented at approximately 180 degrees from the direction of the light cast by the light
6 source.

7
8 ~~Fig. 2 is a top plan depicting at least one light source, with a single light source~~
9 ~~shown in this illustration, with optional filter and with at least one light detector, with~~
10 ~~a plurality of light detectors illustrated, proximal to the sample surface. This~~
11 ~~depiction demonstrates an orientation of light detectors relative to the direction of~~
12 ~~light cast on the sample surface with one light detector oriented at approximately 45~~
13 ~~degrees to the direction of the light cast by the light source and a second light detector~~
14 ~~oriented at approximately 180 degrees from the direction of the light cast by the light~~
15 ~~source. In this illustration the light detectors are in the same plane as the light from~~
16 ~~the light source. The light detector outputs are illustrated as providing inputs to~~
17 ~~spectrometers. The outputs may be combined to provide a single input to a single~~
18 ~~spectrum-measuring and detecting instrument or may separately form inputs to~~
19 ~~separate spectrometers. For the case of a single measuring instrument, light shutters~~
20 ~~may be used and alternately activated to provide light input from each measuring~~
21 ~~location separately in series, thus producing two spectra from different depths or~~
22 ~~locations of a sample.~~

23
24 Fig. 2A is a section elevation view of Fig 2 with the sample removed.

25
26 Fig. 2B is a top plan depicting a single light source, with optional filter(s) and with
27 multiple light detectors proximal and directed to illuminate the sample surface with
28 both light detectors oriented at approximately 45 degrees to the direction of the light
29 cast by the light source.

30

1

2 ~~Fig. 2B is a top plan depicting a single light source, with optional filter(s) and with~~
3 ~~multiple light detectors proximal and directed to illuminate the sample surface~~
4 ~~demonstrating an orientation of light detectors with both light detectors oriented at~~
5 ~~approximately 45-degrees to the direction of the light cast by the light source. In this~~
6 ~~illustration the light detectors are directed in the same plane which is depicted as~~
7 ~~orthogonal to the light cast by the light source.~~

8

9 Fig. 2C is an elevation view of Fig 2B.

10

11 Fig. 2D is a section from Fig. 2C depicting a shielding method or apparatus, e.g., in
12 the form of a bellows or other shielding article shielding the light detector from
13 ambient light and directing the light detector to detect light spectrum output from the
14 sample.

15

16 Fig. 2E is a detail of a shielding device between the light detector of Fig. 2 and a
17 sample. Shown in this illustration is a shield in the form of a bellows. Other
18 shielding apparatus and methods will provide like shielding structure.

19

20 Fig. 3 is a top plan depicting an alternative embodiment of a light source and light
21 detector configuration where the light source is communicated by fiber optics.

22

23 ~~Fig. 3 is a top plan depicting an alternative embodiment of a light source and light~~
24 ~~detector configuration where the light source is communicated by fiber optics from an~~
25 ~~illumination source, e.g., a lamp such as the lamp at a spectrometer, light detection is~~
26 ~~provided by light sensors, e.g., fiber optics or other means of transmission, positioned~~
27 ~~in varying relationships to the light source.~~

28

29

30

1 Fig. 3A is a section from Fig. 3. The light source and light detector may be as
2 described for Fig. 1. Alternative light source may be provided by a plurality of light
3 sources, which may be sequentially fired light emitting diodes emitting discrete
4 wavelengths; where LEDs are employed, the light sensor or light detector may be a
5 broadband photodiode detector central to concentrically positioned LEDs. Fig. 3A
6 illustrates light sources or lamps (and alternatively LEDs) concentrically positioned
7 around a broadband light detector (and alternatively a broadband photodiode detector
8 255, such light sources as well as the light sources 120/LEDs 257, can be placed in
9 other arrangements. These and other configurations also apply in the use of filtered
10 photodetectors 255 and broadband lamp 123 design.

11

12

13 ~~Fig. 3A is a section from Fig. 3 showing an embodiment where light sources 120 or~~
14 ~~lamps 123 are transmitted from a light source 120 or lamp 123 by light source fibers~~
15 ~~which are concentric to at least one detection fiber or light detector 80. The light~~
16 ~~source and light detector may be as described for Fig. 1. Alternative light source may~~
17 ~~be provided by at least one light source, depicted here as a plurality of light sources,~~
18 ~~which may be sequentially fired light emitting diodes emitting discrete wavelengths;~~
19 ~~where LEDs are employed, the light sensor or light detector may be a broadband~~
20 ~~photodiode detector central to concentrically positioned LEDs. While Fig. 3A~~
21 ~~illustrates light sources or lamps (and alternatively LEDs) concentrically positioned~~
22 ~~around a broadband light detector (and alternatively a broadband photodiode detector~~
23 ~~255, it will be recognized that such light sources of this embodiment, as well as the~~
24 ~~light sources 120/LEDs 257 of other embodiments, can be placed in other~~
25 ~~arrangements. These two and other configurations also apply in the use of filtered~~
26 ~~photodetectors 255 and broadband lamp 123 design.~~

27

28 Fig. 3B is a section from Fig. 3 showing an embodiment where light detectors or light
29 detection fibers surround a least one light source or light source fibers. The light

30

1 source and light detector may be as described for Fig. 1. In this representation, the
2 centrally positioned light source may be a lamp or light transmitted from a
3 spectrometer; the light detection may be by fiber optics transmission with discrete
4 bandwidth filters between the fiber optics fiber and the sample limiting the
5 transmission by any single or group of fibers.

6
7 ~~Fig. 3B is a section from Fig. 3 showing an embodiment where light detectors or light~~
8 ~~detection fibers surround a least one light source or light source fibers. The light~~
9 ~~source and light detector may be as described for Fig. 1. Alternative light source and~~
10 ~~light detection may be provided. In this representation, the centrally positioned light~~
11 ~~source may be a lamp or light transmitted from a spectrometer, the light detection~~
12 ~~may be by fiber optics transmission with discrete bandwidth filters between the fiber~~
13 ~~optics fiber and the sample limiting the transmission by any single or group of fibers.~~
14 ~~Alternatively, light source delivery and detection may be by a bifurcated reflectance~~
15 ~~probe; a reflectance probe may provide one or more light delivery sources and one or~~
16 ~~more light detectors providing inputs to one or more spectrometer.~~

17
18 Fig. 4 is a top plan depicting an alternative embodiment of a light source and light
19 detector configuration.

20
21
22 ~~Fig. 4 is a top plan depicting an alternative embodiment of a light source and light~~
23 ~~detector configuration where at least one, and as depicted in this illustration two, light~~
24 ~~sources are communicated by fiber optics from an illumination source, e.g., a lamp~~
25 ~~such as the lamp at a spectrometer or an external lamp under computer control; light~~
26 ~~detection is provided by light sensors, e.g., fiber optics or other means of~~
27 ~~transmission, positioned in varying relationships to the light source detecting the~~
28 ~~output from the sample and providing an input to a spectrometer.~~

29
30

1 Fig. 5 is a top plan depicting an alternative embodiment of the disclosure in a hand
2 held case showing a light source and light detector configured in a sampling head. In
3 this embodiment at the sampling head at least one light source, which may be a
4 tungsten halogen lamp, is positioned in relation to discrete-wavelength filtered
5 photodetectors. A shield is illustrated as an ambient shield. The operation of this
6 embodiment is seen in Fig. 1E wherein all components are encased within the case
7 250.

8
9
10 ~~Fig. 5 is a top plan depicting an alternative embodiment of the disclosure in a hand~~
11 ~~held case showing a light source and light detector configured in a sampling head. In~~
12 ~~this embodiment at the sampling head at least one light source, which may be a~~
13 ~~tungsten halogen lamp, is positioned in relation to discrete-wavelength filtered~~
14 ~~photodetectors. A method or article is required to shield the photodetectors from the~~
15 ~~light source and from ambient light which is illustrated as an ambient shield~~
16 ~~provided, for example, by pliable or compressible foam, bellows and by other such~~
17 ~~materials or structures. In this illustration the sampling head is arranged so that the~~
18 ~~photodetectors are concentrically arrayed in relation to the light source. The light~~
19 ~~source may be communicated by fiber optics from an illumination source, e.g., a lamp~~
20 ~~within the case or by placement of a lamp within the sampling head, e.g., the~~
21 ~~broadband output lamp, e.g., tungsten halogen, is physically located centrally to~~
22 ~~concentrically arrayed photodetectors. The light source may be present to be in~~
23 ~~contact with the sample surface or proximal to the sample surface. Electrical~~
24 ~~communication is effected between the light source and photodetectors and a~~
25 ~~computer processor. The photodetectors, fulfilling a spectrometer or spectral~~
26 ~~measurement function, provide the input which will be processed with~~
27 ~~microprocessor stored calibration algorithms to produce an output representing one or~~
28 ~~more parameters of the sample. The operation of this embodiment is seen in Fig. 1E~~
29 ~~wherein all components are encased within the case 250.~~

30

1 Fig. 5A is a side elevation of Fig 5 depicting a sample positioned on the sampling
2 head.

3
4 Fig. 5B is an illustration of the embodiment of Fig. 5 where the sampling head 260 is
5 in the form of a clamp 263. The light detector 80 is depicted as a fiber optic fiber
6 transmitting spectrum from the sample to an array of filtered 130 photodetectors 255
7 or a spectrometer 170. The output 82 will be managed as shown in Fig. 1D or 1E.

8
9
10 ~~Fig. 5B is an illustration of the embodiment of Fig. 5 where the sampling head 260 is~~
11 ~~in the form of a clamp 263 having at least two clamp jaws 266 which receive and~~
12 ~~secure within at least one jaw 266 structure at least one lamp 123 and in at least one~~
13 ~~clamp jaw 266 structure at least one light detector 80 such that the jaws 266, when~~
14 ~~the clamp 263 is closed, receive a sample 30 positioned to have the at least one lamp~~
15 ~~123 and the at least one light detector 80 proximal the sample surface 35. The light~~
16 ~~detector 80 is depicted as a fiber optic fiber transmitting spectrum from the sample to~~
17 ~~an array of filtered 130 photodetectors 255 or a spectrometer 170. The output 82 will~~
18 ~~be managed as shown in Fig. 1D or 1E.~~

19
20 Fig. 5C is a section from Fig. 5B of the array of filtered 130 photodetectors 255. A
21 positioning structure 79 secures and positions the light detector 80 relative to the
22 filtered 130 photodetectors 255.

23
24
25 ~~Fig. 5C is a section from Fig. 5B of the array of filtered 130 photodetectors 255. The~~
26 ~~spectrum from the sample detected by fiber optic fiber 80 which is contained and~~
27 ~~positioned to transmit the detected spectrum from the sample so that the fiber is~~
28 ~~central to a concentrically arrayed filtered 130 photodetectors 255. A positioning~~

29
30

1 ~~structure 79 secures and positions the light detector 80 relative to the filtered 130~~
2 ~~photodetectors 255.~~
3
4 Fig. 5D is an illustration of the embodiment of Fig. 5 where in at least one clamp jaw
5 266 structure at least one arc photodetector array 90.
6
7
8 ~~Fig. 5D is an illustration of the embodiment of Fig. 5 where the sampling head 260 is~~
9 ~~in the form of a clamp 263 having at least two clamp jaws 266 which receive and~~
10 ~~secure within at least one jaw 266 structure at least one lamp 123 and in at least one~~
11 ~~clamp jaw 266 structure at least one arc photodetector array 90 such that the jaws~~
12 ~~266, when the clamp 263 is closed, receive a sample 30 positioned to have the at least~~
13 ~~one lamp 123 and the at least one arc photodetector array 90 proximal the sample~~
14 ~~surface 35. The arc photodetector array 90 is depicted as an array of filtered 130~~
15 ~~photodetectors 255 which will preferably be equidistant from the lamp 123 when a~~
16 ~~sample 30 is received. The output 82 will be managed as shown in Fig. 1D or 1E.~~
17
18 ~~Fig. 5E is a section of the photodetector 255 array of Fig. 5D.~~
19
20 Fig. 6 is a top plan depicting an additional embodiment of the disclosure in a hand
21 held case. The operation of this embodiment is seen in Fig. 1F wherein all
22 components are encased within the case 250.
23
24 ~~Fig. 6 is a top plan depicting an additional embodiment of the disclosure in a hand~~
25 ~~held case showing a light source and light detector configuration in the form of a~~
26 ~~sampling head. In this embodiment at the sampling head at least one light source is~~
27 ~~positioned in relation at least one photodetector. A method or article is required to~~
28 ~~shield the light source and light detector or photodetectors from ambient light is~~
29 ~~illustrated as an ambient shield provided, for example, by pliable or compressible~~
30

1 ~~foam, bellows, as indicated by the structure of Fig. 2D and 2E and by other articles~~
2 ~~equally recognized as providing such shielding structure. In this illustration the~~
3 ~~sampling head is arranged so that the at least one light detector or photodetector is~~
4 ~~central to concentrically arrayed discrete wavelength light emitting diodes. In this~~
5 ~~embodiment the light emitting diodes fulfill the function of light source and are~~
6 ~~sequentially fired or lighted with the spectrum output detected by the at least one light~~
7 ~~detector or photodetector. The operation of this embodiment is seen in Fig. 1F~~
8 ~~wherein all components are encased within the case 250.~~

9
10 Fig. 6A is a section elevation of Fig 6 depicting the sampling head showing the
11 ambient shield, light emitting diodes and photodetector or light detector fixed by
12 affixing articles within the sampling head. The output from the light detector is
13 depicted as well as is the case.

14
15 Fig. 6B is an elevation representative of an additional embodiment of the disclosure
16 of this invention and of the embodiment of Fig. 6.

17
18 ~~Fig. 6B is an elevation representative of an additional embodiment of the disclosure~~
19 ~~of this invention and of the embodiment of Fig. 6 where a sampling head is affixed in~~
20 ~~a case, light detectors are affixed by affixing articles within the sampling head. The~~
21 ~~sampling head receives a sample which is positioned to be illuminated by a light~~
22 ~~source lamp. This embodiment depicts the case as having a cover which serves as an~~
23 ~~ambient shield. Additionally, the structure of the sampling head may be of a~~
24 ~~compressible or pliable foam or a bellows which may provide the structure allowing~~
25 ~~an ambient shield. A light source input is depicted for example from a spectrometer.~~
26 ~~Outputs from the photodetectors are depicted which may be inputs to a spectrum~~
27 ~~measuring instrument such as a spectrometer with a detector.~~

1 Fig. 6C is a plan view of the embodiment of Fig. 6B illustrating a plurality of light
2 detectors, illustrated here as fiber optic light detectors. Shown in this illustration are
3 two light detectors with one proximal the light source and another distal from the
4 light source.

5
6
7 ~~Fig. 6C is a plan view of the embodiment of Fig. 6B illustrating a plurality of light~~
8 ~~detectors, illustrated here as fiber optic light detectors. Shown in this illustration are~~
9 ~~two light detectors with one proximal the light source and another distal from the~~
10 ~~light source with the purpose being to provide two different pathlengths, shallow and~~
11 ~~deep, by taking the difference between the far or deep spectrum and the near or~~
12 ~~shallow spectrum data of greater accuracy can be obtained. This difference method~~
13 ~~provides a pathlength correction to improve concentration or property or sample~~
14 ~~characteristic predictions.~~

15
16 Fig. 6D is a section detail view from Fig. 6B illustrating the light source, lamp, light
17 source securing article, case, sampling head, light detectors positioned proximal and
18 distal from the light source, light source input and light detector outputs.

19
20 Fig. 6E is an elevation view of an embodiment of the disclosure of Fig. 6 wherein the
21 sampling head structure provided the ambient shield structure.

22
23 Fig. 6F is a section detail from Fig. 6E showing light detectors affixed within the
24 sampling head ambient shield positioned proximal and distal from the light source, a
25 lamp with lamp input, light detector outputs and a case.

26
27 Fig. 7 is a side elevation showing another embodiment in a packing/sorting line form
28 of the disclosure. The light source and light detector are positioned proximal the
29 sample.

30

1
2 Fig. 7 is a side elevation showing another embodiment in a packing/sorting line form
3 of the disclosure illustrating a light source and light detector affixed and positioned
4 by bracket articles, light detector fixture and light source securing articles which will
5 be recognized as structure from which at least one light source and at least one light
6 detector will be suspended, rigidly secured and otherwise positioned including the use
7 of such as rods, bars and other such bracket fixture articles. The at least one light
8 source is positioned to illuminate a sample, depicted in this drawing as an apple. The
9 at least one light detector is positioned by bracket articles and light detector fixture to
10 detect the light spectrum output from the sample. Samples, in this illustration are
11 conveyed by a sample conveyor. Total exposure to the at least one light source and at
12 least one light detector will be limited by the nature of the sample being interrogated
13 and of the embodiment, i.e., sampling time may be limited in a packing/sorting line
14 application for apples, to 5ms or less. However, it will be recognized that other
15 sampling times and strategies will be within the realm of use for the invention
16 disclosed herein. The at least one light detector monitoring the sample depicted is
17 directed to detect light at approximately 30 degrees relative to the direction of the
18 light cast from the at least one light source, although various other placements of light
19 detector(s) relative to light source(s) can also be utilized. The light source and light
20 detector are positioned proximal the sample. The light source lamp may be powered
21 from a spectrometer or externally controlled by the CPU. The light detector may be a
22 single fiber optic fiber with the light spectrum detected forming the input to a
23 spectrum detection instrument such as a spectrometer. The processing of the light
24 spectrum detected is as described and set out in Fig. 1C and 1D

25

26 Fig. 7A is a section elevation of Fig 7 depicting the light source, and sample
27 conveyance system, bracket fixture, light source securing article, lamp input and
28 spectrometer as a sample moves into illumination from the light source and toward
29 the light detector.

30

1 Fig. 7B is a section elevation of Fig 7 depicting the light detector, and sample
2 conveyance system, bracket fixture, light detector fixture, light detector output,
3 spectrometer, and detector as a sample moves toward and under the light detector.
4
5 Fig. 7C is an elevation depicting at least one light detector 80 and as shown a
6 plurality of light detectors 80 representative of measurements of a plurality of
7 spectrum regions.
8
9 ~~Fig. 7C is an elevation depicting at least one light detector 80 and as shown a~~
10 ~~plurality of light detectors 80 representative of measurements of a plurality of~~
11 ~~spectrum regions. A filtered 130 light detector 80 is representative of the detection of~~
12 ~~spectrum of 700 to 925nm, another light detector 80 is representative of detection of~~
13 ~~red pigments and chlorophyll in the 500 to 699nm range and the 926 to 1150 nm~~
14 ~~range, another light detector 80 is representative of detection of the yellow pigment~~
15 ~~region in the range of 250 to 499 nm. Two additional light detectors 80 are shown~~
16 ~~positioned opposite a light source 120 lamp 123 such that the sample will pass~~
17 ~~between the lamp 123 and light detector 80 and is representative of an input to~~
18 ~~reference spectrometers 170 separately operating in the 250-499 nm range and 500-~~
19 ~~1150 nm range. Where the sample is an apple it will be expected that the reference~~
20 ~~channels additionally will not detect spectrum out of the sample and will indicate the~~
21 ~~presence or absence of a sample. This reference channel information can then be~~
22 ~~used to aide in the selection of optimal sample spectra to use for prediction.~~
23 ~~Shielding may be utilized between the light source and the light detectors and or~~
24 ~~sample, e.g., options include but are not limited to 1) a light shield as a curtain may~~
25 ~~extend from a bracket fixture between the light source and light detectors reducing~~
26 ~~the direct exposure of the light detectors to the light source, 2) the light shield may~~
27 ~~extend between the light source and light detectors and sample wherein an aperture~~
28 ~~will be formed in the light shield between the light source and sample limiting~~
29 ~~surface reflection from the sample to the light detectors and 3) the light shield may~~
30

1 ~~provide filter function, e.g., heat blocking, cutoff and bandpass, between the light~~
2 ~~source and sample limiting the possibility of heat or burn damage to the sample.~~

3

4 Fig. 7D is a section from Fig. 7C showing the lamp 123 oriented to illuminate the
5 sample from the side. As illustrated, the sample as an apple is illuminated from the
6 stem side.

7

8 Fig. 7E is a section from Fig. 7C showing one of the light detectors 80.

9

10 Fig. 8 is a side elevation showing an additional embodiment of the apparatus
11 disclosed in Fig. 7.

12

13 ~~Fig. 8 is a side elevation showing an additional embodiment of the apparatus~~
14 ~~disclosed in Fig. 7 wherein at least one light shield is positioned by a bracket fixture~~
15 ~~article to separate the at least one light source from the at least one light detector as a~~
16 ~~sample is conveyed by a sample conveyor under and past a light source toward and~~
17 ~~under a light detector. The light shield may be a curtain and is depicted in Fig. 8 as a~~
18 ~~curtain composed of two portions, each suspended from a bracket fixture. The at~~
19 ~~least two curtain portions overlap and separate as the sample passes.~~

20

21 Fig. 8A is a section elevation of Fig 8 depicting the light shield and at least one
22 curtain, light source, and sample conveyance system as a sample moves into contact
23 with and under the light shield. Fig. 8B is a section elevation of Fig 8 depicting the
24 light shield, at least one curtain, light detector and sample conveyance system as a
25 sample moves into contact with and under the light shield.

26

27 Fig 9 is an elevation depicting an additional embodiment of the invention
28 demonstrating at least one light detector 80 having an output 82 to a spectrometer 170
29 having a detector 200. A collimating lens 78 is intermediate the at least one

30

1 detector 80 and a sample 30. The detector 80 positioned to detect light from the
2 sample 30. Light source 120 lamps 123, a case 250 intermediate the light source 120
3 lamp 123 and a sample 30 conveyed by sample conveyor 295. An aperture 310
4 allows illumination of the sample 30 by the at light source 120 lamp 123. A least
5 light shutter 300 intermediate the light source 120 lamp 123 and aperture 310. The
6 light shutter 300 operable by shutter operating means. The shutter control means 305
7 receiving control signals from a CPU 172 having shutter operating control output
8 307. A reference light transmitting means 81 including fiber-optics receiving
9 reference light output from the light source 120 lamp 123. A reference light shutter
10 301 intermediate the light source 120 lamp 123 and the reference light transmitting
11 means 81. The reference light shutter 301 operable by shutter control means 305.
12 The reference light shutter 301 shutter control means 305 receiving control signals
13 from a CPU 172 having a shutter operating control output 307. The reference light
14 transmitting means 81 providing an input to the spectrometer 170. The CPU 172
15 providing lamp power output 125 to the light source 120 lamp 123. The spectrometer
16 170, receiving input from reference light transmitting means 81 having output 82
17 received as in input to the CPU 172. The spectrometer output 82 capable of A/D
18 conversion to form input to the CPU 172. The spectrometer 170, receiving input
19 from detector output 82 received as in input to the CPU 172. Mounting means
20 indicated as described in other figures to light sources 120 lamps 123, detectors 80,
21 shutters 300, shutter control means 305, reference light transmitting means 81 and
22 case 250. Encoder/pulse generator 330 input to CPU 172 providing sample conveyor
23 295 movement data. Computer program to operate CPU 172 in data collection and
24 control functions.

25

26 Fig. 10 illustrates using spectroscopic sensors for measuring fruits and vegetables while in
27 motion on a sample conveyor 295. Shown is a sample 30 with proximity sensing means 340.
28 Demonstrated is the sample conveyor 295, a case 250, collimating lens 78.

29

30

1 Fig. 10A is a section from Fig. 10 illustrating the proximity sensing means 340 in the form
2 of reflectance means.
3
4 Fig. 11 illustrates the manner of taking a reference measurement of the light source 120
5 lamp(s) 123 where intensity vs. wavelength output can also be obtained using reflecting
6 means 360. Reflecting means 360 may be inserted via an aperture 310, for example in a case
7 250, when a reference measurement is to be made as dictated by reflecting control means
8 308 as an output from a CPU 172. The CPU 172, via means, will detect the presence or
9 absence of a sample 30 and, when a sample 30 is absent for "n" time increments or sample
10 conveyor 295 movements will provide a reflecting control means 308 control signal to
11 reflecting position means 306, e.g., linear actuator or rotary solenoid operated by means,
12 e.g., mechanical driven by electrical, pneumatic, hydraulic or other power means.
13
14 Fig. 12 and 13 illustrate the mechanical insertion of reference means 430 in or near the
15 location where actual sample 30 is normally measured. Insertion is by insertion means
16 including but not limited to an actuator system 400.
17
18 Fig. 14 and 14A illustrate a means of reducing the width of apparatus structure by mounting
19 light source 120 lamps 123 distal from a sample 30 with spectrum from the sample 30
20 directed by reflecting means 360 and lens 78 or reference light transmission means 320 with
21 spectra received via apertures 310.
22
23 Fig. 15 and 15A illustrates spectra detection from sample 30 other than discrete increments,
24 such as apples, including, for example potato chips, where light source 120 lamps 123
25 illuminate the sample(s) 30 with detectors 80 receiving input with light detector output 82
26 conveyed as input to spectrometers 170 detectors 200. In this illustration a lens 130 is
27 depicted between the sample 30 and the detector 80. Illustrations 15 and 15A depict in
28 detail, with filter 130 and mounting means, a single detector 80.
29
30

1 A CPU 172, controlled by computer program, is not depicted in Fig. 10, 10A, 11, 12, 13, 14,
2 14A, 15 or 15A as a person of ordinary skill will appreciate such structure from viewing
3 other drawings presented herein.

4

5

6

Detailed Description

7 The apparatus and method disclosed herein is illustrated in Fig. 1 through 8.
8 Fig. 1C, 1D, 1E and 1F are flow diagrams demonstrating the method of this
9 invention. The flow diagram Fig. 1C is representative of all embodiments of this
10 disclosure. The flow diagram Fig. 1D illustrates one or more light sources 120 and
11 multiple channels from light detector 50 through final prediction of sample
12 characteristic. Fig. 1D demonstrates the method and apparatus of this disclosure
13 illustrating the light source(s) 120, which may be lamps 123 or other light sources,
14 which illuminate a sample 30 interior 36, light collection channels 1...n, composed
15 for example of fiber optic fibers 80 or photodetectors 255, e.g., light detector 1...n, of
16 the spectra from a sample 30 delivered as input 82 to a spectra measuring device,
17 shown here as spectrometer(s) 1...n. 170. In the preferred embodiment a light source
18 120 with lamp 123 is external to the spectrometer and is controlled by a CPU 172
19 which triggers power 125 to the light source 120 lamp 123. Spectrometer 1...n 170
20 channels output 1...n are converted from analog to digital by A/D converters 1...n
21 171 and become, for each channel, input to a CPU 172. The CPU 172 is computer
22 program controlled with each step, following the CPU 172 in this flow diagram is
23 representative of a computer program controlled activity. A CPU 172 output is
24 provided for each channel 1...n where the steps of 1) calculation of absorbance
25 spectra 173 occurs for each channel 1...n, 2) combine absorbance spectra 174 into a
26 single spectrum encompassing the entire wavelength range detected from the sample
27 by spectrometers 1...n 170, 3) mathematical preprocessing or preprocess 175, e.g.,
28 smoothing or box car smooth or calculate derivatives, precedes 4) the prediction or
29 predict 176, for each channel, comparing the preprocessed combined spectra 175 with
30

1 the stored calibration spectrum or calibration algorithm(s) 177 for each characteristic
2 1...x 178, e.g., Brix, firmness, acidity, density, pH, color and external and internal
3 defects and disorders, for which the sample is examined, followed by 5) decisions or
4 further combinations and comparisons of the results of quantification of each
5 characteristic, 1...x, e.g., determination of internal and or external defects of disorders
6 179, 180; determination of color 181; determination of indexes such as eating quality
7 index 182, appearance quality index 183 and concluding with sorting or other
8 decisions 184. Sorting or other decisions 184 may for example be input process
9 controllers to control packing/sorting lines or may determine the time to harvest, time
10 to remove from cold storage, and time to ship. The apparatuses depicted in Fig. 1
11 through 8 do not all illustrate the entire flow diagram sequence from illumination of
12 sample 30 through determination of the predicted result as is depicted in Fig. 1C, 1D,
13 1E and 1F. For signal processing illustrations, reference is made to the indicated
14 drawings.

15 Fig. 1E is a flow diagram demonstrating the method and apparatus illustrating
16 the light source(s) 120 as a broad band source, such as a tungsten halogen lamp,
17 which illuminates a sample 30; at least one, but in an embodiment a plurality, of
18 discrete wavelength filtered (bandpass) photodetectors 255 having filters 130 provide
19 spectrum detection for light collection channels 1...n (photodetector 1...n) of the
20 spectra from a sample 30. In this embodiment a light source 120 with lamp 123 is
21 controlled by a CPU 172 which triggers power 125 to the light source 120 lamp 123.
22 The spectrum detected from the sample surface 35 may be communicated by fiber
23 optic fibers as light detectors 80 to the photodetectors 255. The management of the
24 detected spectra is as described for Fig. 1D. An alternative to this embodiment may
25 use an AOTF, (acousto-optic tunable filter) to replace the at least one or a plurality of
26 photodetectors 255 as the spectrum detection device.

27 Fig. 1F is a flow diagram demonstrating the method and apparatus illustrating
28 the light source(s) provided by at least one, but in an embodiment a plurality of
29 discrete wavelength light emitting diodes 257, which may be sequentially fired or
30

1 lighted by a CPU trigger for power 125 to illuminate a sample 30; at least one
2 broadband photodetector 255 and, in an alternative embodiment a least one
3 broadband photodetector 255 for each LED 257, provide spectrum detection for light
4 collection channels 1...n (photodetector 1...n) of the spectra from a sample. The
5 management of the detected spectra is as described for Fig. 1D. Alternative light
6 sources for this embodiment include but are not limited to tunable diode lasers, laser
7 diode and a filter wheel placed between the light source(s) and sample or between the
8 sample and photodetector(s).

9 Fig. 1, 1A and 1B depict an embodiment of a Nondestructive Fruit Maturity
10 and Quality Tester 1 for measuring and correlating characteristics of fruit with
11 combined Visible and Near Infra-Red Spectrum showing an embodiment of the
12 disclosure illustrating a sample holder 5 having a securing or spring biasing article 9
13 urging a holding article 12 against and in contact with a sample 30. The holding
14 article depicted in Fig. 1 is illustrated as essentially a hemisphere sized to receive a
15 sample 30. The sample has a sample surface 35. At least one light source 120 will
16 be employed proximal the sample surface 35. The light source 120 is comprised of at
17 least one lamp 123, optional filters 130. Here illustrated are two light sources 120
18 each directed essentially orthogonally to the sample surface 35 and illuminating the
19 sample 30 approximately 60 TO 90 degrees relative to each other. A light detector
20 80 is depicted as directed to detect light from the sample surface 35 at approximately
21 30 TO 45 degrees relative to the direction of the light cast from either light source
22 120. The light detector 80 is illustrated as positioned by a light detector fixture 50
23 having a light detector securing or spring biasing article 60 placing, holding and or
24 urging a light detector 80 into contact with the sample surface 35. Monitoring of the
25 light source 120 is depicted by light detectors 80 depicted as directed toward the lamp
26 123 output; the output 82 of these reference light detectors 80 is detected by a
27 reference spectrometer 170; an alternative to the use of two spectrometers 170 will be
28 the sequential measurement of reference light detectors 80 and the light detector 80
29 directed to the sample surface 35. All light detector 80 are fixed by light detector
30

1 fixtures 50 by light detector securing or spring biasing articles 60 to a plate 7 or other
2 containing device such as a case. The securing article 9 urging the holding article 12
3 against the sample 30 also urges the sample against the light detector 80. The
4 securing article 9 and holding article 12 in combination with the light detector 80 and
5 light detector securing article 60 secure and prevent the sample 30 from movement.
6 The sample 30 is shown, in Fig. 1, as an apple. The light sources 120 may be, for
7 example, tungsten/halogen lamps. An optional filter 130 or filters 130 functioning as
8 heat block, bandpass and or cutoff filters, separately or in combination, may be
9 positioned between the lamp 123 and the sample 30 or between the sample 30 and the
10 light detector 80. The light sources 120 may be lamps 123, provided for example by
11 external 50Watt, 75 Watt, or 150 Watt lamp sources controlled by a CPU 172.
12 Power 125 can be provided by power supply from a spectrometer 170 or from an
13 alternate power supply. Both the light source(s) and the spectrometer(s) are
14 controlled by a CPU 172 and their operation can be precisely controlled and
15 optimally synchronized using digital input/output (I/O) trigger. The light detector 80,
16 shown here as a fiber-optic sensor, provides a light detector output 82 which
17 becomes the input to a spectrometer 170, or other spectrum measuring or processing
18 instrument, which is detected by a detector 200, e.g., at least one light detection
19 device or article, such as a CCD array which may be a CCD array within a
20 spectrometer 170. The sample holder 5, light detector fixture 50 and light detector
21 securing article 60 and light sources 120 with light source securing article 122 are
22 affixed to a plate 7, for experimental purposes but will be otherwise enclosed and or
23 affixed in a container, case, cabinet or other or other fixture for commercial purposes,
24 e.g., applications include and are not limited to sample measurements on high speed
25 sorting and packing lines, harvesters, trucks, conveyor-belts and experimental and
26 laboratory. Other brackets, fixtures or articles may be employed to secure or position
27 either sample holders 5, light detectors 50 and or samples 30 requiring only that the
28 device or method used retain the sample 30 in position relative to the light source 120
29 and light detector 50 during the period of measurement; fixing methods including
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1 welds, bolts, screws, glue, sheet metal forming and other methods may be used to
2 secure such items for either experimental or commercial purposes..

3 Fig. 2, 2A, 2B, 2C, 2D and 2E depicts an alternative embodiment of the
4 Nondestructive Fruit Maturity and Quality Tester 1 depicting a single light source
5 120, with lamp 123 and optional filter 130 and with multiple light detectors 80 in
6 contact with the sample surface 35. This depiction of the relative positioning of the
7 light detectors 80 with the sample 30 or sample surface 35 is directed to the shielding
8 of the light detector 80 from ambient light and is intended to demonstrate either direct
9 contact between the light detector 80 and the sample surface 35 or shielded a shield
10 84 composed, for example, by bellows, a foam structure or other pliable or
11 compressible article or apparatus providing a sealing structure or shield method of
12 insuring that the light detector 80 is shielded from ambient light and light from the
13 light source 120 and receives light spectrum input solely from the sample 30. The
14 positioning of the light source 120 relative to the light detectors 80 illustrate a
15 positioning of one light detector 80 at angle theta of approximately 45 degrees to the
16 direction of the light as directed by the light source 120 to illuminate the sample 30.
17 The second light detector 80, in this illustration, is at angle gamma of approximately
18 180 degrees to the direction of the light as directed by the light source 120. The
19 positioning of the light detector 80 at approximately 180 degrees to the direction of
20 the light as directed by the light source 120 may be a position utilized for the
21 detection of internal disorders within the sample, e.g., internal disorders within
22 Tasmania Jonagold apples, such as water core, core rot, internal
23 browning/breakdown, carbon dioxide damage, and, in some cases, insect
24 damage/infestation. The light detectors 80 in this illustration are suggestive of the
25 many light detector 80 positions possible with the positioning dependent on the
26 sample and the characteristic or characteristics to be measured or predicted. In this
27 illustration the light detectors 80 are positioned to detect within the same plane as the
28 light directed from the light source 120. The orientation of 180 degrees between light
29 source 120 and light detector 80 will be preferred for smaller samples. Larger
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1 samples 30 will attenuate light transmission thus requiring the location of the light
2 detector 80 proximal the light source 120 to insure exposure to light spectrum output
3 82 characteristic of the sample 30. The orientation of the light source 120 and light
4 detectors 80 is sensitive to fruit size, fruit skin and fruit pulp or flesh properties. The
5 orientation where the sample 30 is an apple will likely preclude a 180 degree
6 orientation because of limitations in proximity and intensity of the light source 120 as
7 being likely to damage or burn the apple skin. However, orange skins are less
8 sensitive and may withstand, without commercial degradation, a light source 120 of
9 high intensity and closely positioned to the orange surface. Generally, the signal
10 output or light detector output 82 is dependent on the orientation of the light source
11 120 relative to the sample 30 and sample surface 35 and the light detector 80.

12 Fig. 2B and 2C depict an alternative orientation of light detectors 80 where
13 the light detectors 80 are oriented at angle theta of approximately 45 degrees to the
14 direction of the light as directed by the light source 120. This illustration
15 demonstrates two light detectors 80 positioned approximately 90 degrees apart and
16 positioned to detect light from approximately the same plane. One of ordinary skill
17 in the art will recognize from these illustrations that the positioning of the light
18 source or light sources and light detector or detectors will depend on the
19 measurement intended. Fig. 2D and 2E depict a shielding method or apparatus, e.g.,
20 in the form of a bellows or other shield 84 article shielding the light detector from
21 ambient light and enabling the light detector to solely detect light spectrum output
22 from the sample. The shield 84 structure may be formed of a flexible or pliant
23 rubber, foam or plastic which will conform to the surface irregularities of the sample
24 and will provide a sealing function between the shielding material and sample surface
25 which will eliminate introduction of ambient light into contact with the light detector.
26 The shield 84 is depicted in the form of a bellows in Fig. 2D and 2E.

27 Fig. 1, 2 - 4, 6, 7 and 8 depict light sources which may be provided by
28 spectrometers 170 (as in the case of Fig. 3) or external lamps controlled by CPU 172
29 (as in case of Figs. 1, 2, 4 - 8). In all cases of Fig. 1 - 4, 6, 7, and 8, tungsten halogen
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1 lamps or the equivalent are used which generally produce a spectrum within the range
2 of 250-1150 nm when the filament temperature is operated at 2500 to 3500 degrees
3 kelvin. The light source, for the invention disclosed herein may be a broadband
4 lamp, which for example, but without limitation, may be a tungsten halogen lamp or
5 the equivalent, which may produce a spectrum within the range of 250-1150 nm;
6 other broadband spectrum lamps may be employed depending upon the sample 30,
7 characteristics to be predicted, and embodiment utilized The light detector 80 output
8 82 in these embodiments will generally be received by a spectrometer 170 having a
9 detector 200 such as a CCD array.

10 Fig. 3, 3A and 3B depict an alternative embodiment of a Nondestructive Fruit
11 Maturity and Quality Tester-Combined Unit 15 of a combined unit 126 having a
12 combined source/detector 135. The source of light and method of light detection in
13 this embodiment may be a light source 120, lamp 123 and light detector 80
14 configuration where the light source 123 lamp 123 is communicated by fiber optics
15 from an illumination source, e.g., a lamp such as the lamp at a spectrometer 170; light
16 detection is provided by light detectors 80, e.g., fiber optics or other manner of light
17 transmission, positioned in varying relationships to the lamp 123 as shown in Fig. 3A
18 and 3B. Fig. 3A is a section from Fig. 3 showing the combined unit 126 where a
19 combined source/detector 135 has an alternative source of light and light detection;
20 the source of light, depicted as a plurality of sources, may be sequentially fired light
21 emitting diodes 257 emitting discrete wavelengths; the light detection may be a
22 broadband photodiode detector 255 central to concentrically positioned LEDs. The
23 combined unit 126 and sample holder 5 are mounted to a plate 7 or other mounting or
24 containing fixture, case, cabinet or other device suitable for commercial or
25 experimental purposes, for example with a bracket or other mounting article, so as to
26 be fixed or as to have a spring or other biasing function to urge the combined unit 126
27 and sample holder 5 against the sample. A light shield 84, as depicted in Fig. 2D and
28 2E may be used between the combined source/detector 135 and the sample surface
29 35. Fig. 3B is a section from Fig. 3 showing an additional embodiment of a
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1 combined unit 126 where a centrally positioned light source 120 lamp 123, for
2 example light via fiber optics from a tungsten halogen lamp, is concentric to at least
3 one and, as depicted here a plurality, of discrete wavelength photodetectors. The
4 output of the at least one detection fibers or light detectors 80 is the input to a
5 spectrometer 170 or other spectral measuring instrument such as a photodetector 255.
6 Depicted is a spectrometer 170 having a detector 200. Alternatively, light source
7 delivery and detection for the embodiment of Fig. 3B may be by a bifurcated
8 reflectance probe; alternatively, it is recognized that a reflectance probe may provide
9 one or more light delivery sources and one or more light detectors providing inputs to
10 one or more spectrometer. While Fig. 3A illustrates LEDs 257 concentrically
11 positioned around a broadband photodiode detector 255, it will be recognized that the
12 LEDs of this embodiment, as well as the light sources 120 of other embodiments, can
13 be placed in other arrangements, e.g., the photodiode detector 255, as well as the
14 detectors 80 of other embodiments, can be 180 degrees opposite a circle of LEDs 257
15 and the sample 30 placed between the LEDs 257 and the photodiode detector 255,
16 e.g., for cherries or grapes; alternatively, the LEDs 257 can be placed on an arc,
17 equidistant and 180 degrees opposite from the photodetector 255 in relationship to
18 the sample 30. These two arrangements are suggestive of the positioning
19 relationships of LEDs 257 (light sources 120), photodiode detectors 255(light
20 detectors 80) and samples 30 as well as the instance where other types of light source
21 and detectors are employed including, for example, the use of filtered photodetectors
22 255 with a broadband lamp 123, as illustrated in Fig. 5. In each embodiment the
23 particular sample 30 type combined with the particular characteristics to be predicted
24 will dictate the pattern of light source 120 and light detector 80 in relation to the
25 sample 30. Additionally, it is to be recognized that light source used herein includes
26 broadband lamps such as the tungsten halogen lamp, LEDs and other light emitting
27 devices; light detectors used herein includes fiber optic fibers, photodiode detectors
28 and other devices sensitive to and capable of detecting light.

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1 Fig. 4 is a top plan depicting an alternative embodiment of a Nondestructive
2 Fruit Maturity and Quality Tester 1 showing at least one light source 120 and lamp
3 123 and light detector 50 configuration where at least one, and as depicted in this
4 illustration two, light source 120 and lamps 123 are communicated by fiber optics to
5 or proximal the sample surface 35, from an illumination source, e.g., a lamp 123 or
6 other external light source. Light detection is provided by light detectors 80, e.g.,
7 fiber optics or other method of light transmission. In this embodiment the light
8 sources 120 and light detector 80 are in contact with the sample surface 35. The light
9 detector 80 detects the light spectrum output from the sample 30 and providing light
10 detector input 82 to a spectrum measuring or processing instrument or method
11 including, for example, a spectrometer 170 having a detector 200. For certain
12 samples, the light detector 80 will be inserted into the sample 30 thus effecting a
13 shielding of the light detector 80 from ambient light, e.g., on harvester-mounted
14 applications or in a processing plant where the product will be processed such as
15 sugar beets or grapes. Otherwise, the light shield 84 depicted in Fig. 2D and 2E is
16 applicable to the interrelationship of the sample 30 and sample surface 35 with the
17 light detector 80 and light source 120 and lamp 123. Illustrated in Fig. 4 is the
18 connection of the light detector outputs 82 from the at least one light detector 80
19 forming the input to a spectrum measuring or processing instrument. It will be
20 recognized that each component of this embodiment will be affixed by conventional
21 methods to a plate 7 or other mounting or containing fixture, case, cabinet or other
22 device suitable for commercial or experimental purposes.

23 Fig. 5 is a top plan depicting an alternative embodiment of the Nondestructive
24 Fruit Maturity and Quality Tester 1 in a hand held case 250 showing a light source
25 120 and at least one light detector 80, shown here as six light detectors 80,
26 configuration in the form of a sampling head 260. In this embodiment at the
27 sampling head 260 at least one light source 120 lamp 123 is positioned in relation to
28 light detectors 80 provided by at least one discrete-wavelength photodetector 255.
29 Shown in Fig. 5 are a plurality of discrete-wavelength photodetectors 255, filling the
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1 combined function of light detector 80, and spectrum detecting instrument such as a
2 CCD array detector 200. The operation of this embodiment is seen in Fig. 1E
3 wherein all components are encased within the case 250. Electronic and computer
4 communication between the sampling head 260 and the computer control circuitry is
5 via electronic signal cabling 265 or wireless including infrared or other such
6 transmission method or apparatus. The sampling head 260 ambient shield 262 will
7 provide a shielding method or apparatus, e.g., fulfilling the same or similar structural
8 function as the shield 84 in Fig. 2D and 2E, in shielding the at least one photodetector
9 255 and lamp 123 from ambient light. The sampling head 260 and ambient shield
10 262, depicted in Fig. 5 and 5A may be formed from a pliable polyfoam within which
11 the at least one lamp 123 and at least one photodetector 255 may be secured by a
12 fixture article. The material or structure forming the sampling head 260 and ambient
13 shield 262 may be flexible or pliable foam, in the form of a bellows or other shielding
14 article similar to that depicted in Fig. 2D and 2E. The use of a pliable polyfoam to
15 form the ambient shield 262 will serve to seal out or preclude exposure, by a sealing
16 action between a sample surface 35 and the ambient shield 262, of the at least one
17 photodetector 255 and lamp 123 from ambient light. Other shielding apparatus and
18 methods will provide adequate shielding structure including bellows, a case or box
19 enclosing the sampling head 260 and sample 30 or other such article providing
20 shielding structure between ambient light and the interface between the sampling
21 head 260, the at least one photodetector 255 and lamp 123 and the sample 30 and
22 sample surface 35. The operation of this embodiment is seen in Fig. 1E wherein all
23 components are encased within the case 250.

24 Fig. 5 and 5A illustrate the sampling head 260 arranged so that at least one,
25 and as illustrated in Fig. 5, a plurality of discrete-wavelength filtered 130
26 photodetectors 255 are concentrically arrayed in relation to the centrally positioned at
27 least one light source 120. The light source 120 lamp 123 which may be
28 communicated by fiber optics from an illumination source, e.g., a lamp within the
29 case 250 or may, for particular samples 30, e.g., oranges, be present to be in contact
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1 with or closely proximal the sample surface 35. Electrical communication and light
2 communication is effected between the light source 120 and photodetectors 255 and a
3 spectrometer 170 by fiber optics and or wiring, printed circuit paths, cables. The
4 photodetectors 255 fulfill a spectrometer or spectral measurement function, provides
5 the input 82 which will be processed with microprocessor stored calibration
6 algorithm to produce an output representing one or more parameters of the sample.
7 Fig. 5A is a side elevation of Fig 5 depicting a sample positioned on the sampling
8 head.

9 Fig. 5B, 5C, 5D and 5E illustrate embodiment of the invention directed
10 particularly to small samples 30, e.g., grapes and cherries, where the sampling head
11 260 is in the form of a clamp 263 having at least two clamp jaws 266 which receive
12 and secure within at least one jaw 266 structure at least one lamp 123 having a light
13 source input 125 and in at least one clamp jaw 266 structure at least one light detector
14 80 such that the jaws 266, when the clamp 263 is closed, receive a sample 30
15 positioned to have the at least one lamp 123 and the at least one light detector 80
16 proximal the sample surface 35. The light detector 80 is depicted as a fiber optic
17 fiber transmitting spectrum from the sample to an array of filtered 130 photodetectors
18 255 or a spectrometer 170. The output 82 will be managed as shown in Fig. 1D or
19 1E. Fig. 5B depicts a light detector 80 as a fiber transmitting spectrum from a sample
20 30 to be displayed on a filtered 130 photodetector array 255 where the fiber 80 is
21 contained and positioned to transmit the detected spectrum from the sample 30 so
22 that the fiber 80 is central to a concentrically arrayed filtered 130 photodetectors 255.
23 A positioning structure 79, which may be tubes interconnected to position the fiber
24 light detector 80 central to the photodetector array 255, secures and positions the light
25 detector 80 relative to the filtered 130 photodetectors 255. A collimating lens 78 will
26 be positioned between the light detector 80 fiber and the array 255 to insure that light
27 from the light detector 80 is normal to the filtered 130 photodetector array 255. Fig.
28 5F depicts an arc photodetector array 90 received and secured within at least one jaw
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1 266 structure where the photodetectors 255 within the photodetector array 90 are
2 preferably equidistant from the light source 120 or lamp 123.

3 Fig. 6 through 6F illustrate an additional embodiment of the Nondestructive
4 Fruit Maturity and Quality Tester 1. Fig. 6 is a top plan depicting an additional
5 embodiment of the disclosure in a hand held case 250 form showing a light source
6 120 in the form of LEDs 257 and light detector 80, in the form of a photodetector
7 255, configuration in the form of a sampling head 260. With the LED 257 and
8 photodetector 255 configuration, the photodetector 255 is used without filters, i.e.,
9 wavelength bandpass filters, and is sensitive from ~250-1150 nm. Alternative
10 devices or methods for providing light source and light detection includes, but is not
11 limited to diodelasers and other light sources producing a discrete wavelength
12 spectrum. In this embodiment at the sampling head 260 at least one LED 257, and as
13 illustrated in Fig. 6, a plurality of LEDs 257, is positioned in relation at least one
14 photodetector 255. A method or article is required to shield the LEDs 257 and
15 photodetector/photodiode detector 255 from ambient light which is illustrated as an
16 ambient shield 262 including structures of compressible and pliable foam, bellows as
17 indicated by the shield 84 structure of Fig. 2D and 2E and other such materials,
18 structures or articles. In this illustration the sampling head 260 is arranged so that the
19 at least one photodetector/photodiode detector 255 is central to concentrically arrayed
20 discrete wavelength LEDs 257. In this embodiment the light emitting diodes 257
21 fulfill the function of light source and are sequentially fired or lighted with the
22 spectrum output detected by the at least one photodetector/photodiode detector 255.
23 The photodetector 255 output 82 is processed as demonstrated in Fig. 1F.

24 The photodetector 255 is responsive to a broad range of wavelengths, both
25 visible and near-infrared (i.e., ~250-1150 nm). When each LED 257 is fired, the light
26 enters the sample 30, interacts with the sample 30, and re-emerges to be detected by
27 the photodetector 255. The photodetector 255 produces a current proportional to the
28 intensity of light detected. The current is converted to a voltage, which is then
29 digitized using an analog-to-digital converter. The digital signal is then stored by an
30

1 embedded microcontroller/microprocessor. The microcontroller/microprocessor used
2 in the preferred embodiment is an Intel 8051. However, other microprocessors and
3 other devices and circuits will perform the needed tasks. The signal detected by the
4 photodetector 255 as each LED 257 is fired is digitized, A/D converted and stored.
5 After each LED 257 has been fired and the converted signal stored, the
6 microprocessor stored readings are combined to create a spectrum consisting of as
7 many data points as there are LEDs 257. This spectrum is then used by the embedded
8 microprocessor in combination with a previously stored calibration algorithm to
9 predict the sample properties of interest. Signal processing then proceeds as shown
10 in Fig. 1F. Fig. 6A is a section elevation of Fig 6 depicting the sampling head 260
11 showing the ambient shield 262, composed for example of compressible foam or
12 bellows or other such structure, e.g., a rubber plunger, originally designed for a
13 vacuum pick-up tool which looks much like a toilet plunger, but has a more gentle
14 curve and is available in a variety of sizes including 1mm diameter and larger; in
15 certain of these embodiments a 20 mm rubber plunger was used with a pickup fiber
16 optic operating as the "handle" that couples to the plunger. The sample then makes a
17 seal with the plunger prior to measurement. Other devices or methods will also
18 provide the requisite sealing structure, as described in this specification. Also shown
19 are light emitting diodes 257 and light detector/photodiode detector 80 fixed by
20 affixing articles within the sampling head 260. The affixing articles will be
21 composed of bracket articles and other mounting structure recognized by one of
22 ordinary skill. The output 82 from the light detector 80 is depicted as well as the case
23 250 with processing as shown in Fig. 1F..

24 Fig. 6B, 6C and 6D are representative of an additional embodiment of the
25 disclosure of this invention where a sampling head 260 is affixed in a case 250, light
26 detectors 80 are affixed by affixing articles within the sampling head 260. The
27 sampling head 260 receives a sample 30 which is positioned to be illuminated by a
28 light source 120 lamp 123. This embodiment depicts the case 250 as having a cover
29 which serves as an ambient shield 262. Additionally, the structure of the sampling
30

1 head 260 may be of a compressible or pliable foam or a bellows which may provide
2 the structure allowing an ambient shield 262. Ambient light can also be measured
3 after the sample 30 is in place, but before the light source 120 lamp 123 is turned on.
4 This ambient light signal is then stored and subtracted accordingly for subsequent
5 measurements. A light source input power 125 is depicted for example from a
6 spectrometer 170 or may be from a CPU 172 trigger or other external lamp source
7 and/or power supply. Outputs 82 from the light detector/photodiode detectors 80 are
8 depicted and processed as shown in Fig. 1F.

9 Fig. 6E and 6F are representative of an embodiment of the disclosure wherein
10 the lamp 123 is positioned within the sampling head 260. Alternatively, the lamp 123
11 may be positioned by an affixing article within the ambient shield 262.

12 Another embodiment in a packing/sorting line form of the disclosure is
13 depicted in Fig. 7, 7A and 7B illustrating a light source 120 and light detector 80
14 affixed and positioned by bracket articles 275, light detector fixture 50 and light
15 source securing articles 122 which will be recognized as mounting structure from
16 which at least one light source 120 and at least one light detector 80 will be
17 suspended, rigidly secured and otherwise positioned including the use of such as rods,
18 bars and other such bracket article 275 fixtures. The at least one light source 120 is
19 positioned to illuminate a sample 30, depicted in this drawing as an apple. The at
20 least one light detector 80 is positioned by bracket articles 275 and light detector
21 fixture 50 to detect the light spectrum output from the illuminated sample 30.
22 Samples 30, in this illustration are conveyed by a sample conveyor 295. Total
23 exposure to the at least one light source 120 and at least one light detector 80 will be
24 determined by the intensity of the light source used and the nature of the sample
25 being interrogated. For apples, exposure times of 5-10 msec or less are commonly
26 used to provide multiple measurements per apple at line speeds up to 20 fruit/second.
27 The at least one light detector 80 depicted in Fig. 7 illustrates a separation of the light
28 detector 80 from the light source 120 of approximately 90 degrees with both light
29 detector 80 and light source 120 essentially orthogonal to the sample in the same
30

1 plane. However, for each embodiment of this disclosure, the positioning of the light
2 detector(s) 80 and of the light sources(es) 120 relative to each other and relative to
3 the sample is dependent on the characteristics of the sample and of the qualities
4 sought to be measured. For example, the light source 120 may be positioned to be
5 directed essentially orthogonal to the sample surface 30 in a plane oriented 90 degrees
6 from the plane to which the light detector 80 is directed. The light source 120 and
7 light detector 80 are positioned proximal the sample 30. The light source 120 lamp
8 123 may be powered from a spectrometer 170 or other external source, as noted in the
9 discussion of Fig. 1. The light detector 80 may be a single fiber optic fiber with the
10 light spectrum detected forming the output 82 to a spectrum detection instrument
11 such as a spectrometer 170 and detector 200. The processing of the light spectrum
12 detected is as described and set out in Fig. 1C.

13 Another embodiment directed to sorting/packing lines is seen in Fig. 7C, 7D
14 and 7E depicting at least one light detector 80 and as shown a plurality of light
15 detectors 80 representative of measurements of a plurality of spectrum regions. A
16 filtered 130 light detector 80 is representative of the detection of spectrum of 700 to
17 925nm, another light detector 80 is representative of detection of red pigments and
18 chlorophyll in the 500 to 699 nm range and water, alcohols and physical quality (e.g.,
19 firmness, density) information available in the 926 to 1150 nm range, another light
20 detector 80 is representative of detection of the yellow pigment region in the range of
21 250 to 499 nm. Two additional light detectors 80 are shown positioned opposite a
22 light source 120 lamp 123 such that the sample will pass between the lamp 123 and
23 light detector 80 and is representative of an input to two reference spectrometers 170,
24 one monitoring the 250-499 nm wavelength region and the other monitoring the 500-
25 1150 nm region.. Where the sample is an apple it will be expected that the reference
26 channel additionally will not detect spectrum out of the sample and will indicated the
27 presence or absence of a sample. The output of the reference channel(s) can be used
28 as an object locator to determine which spectra from the sample light detector(s) to
29 retain for use in prediction. Shielding may be utilized between the light source 120
30

1 lamp 123 and the light detectors 80 and or sample 30, e.g., options include but are not
2 limited to 1) a light shield 284 as a curtain 285 may extend from a bracket fixture 275
3 between the light source 120 lamp 123 and light detectors 80 reducing the direct
4 exposure of the light detectors 80 to the light source 120 lamp 123, 2) the light shield
5 285 may extend between the light source 120 lamp 123 and light detectors 80 and
6 sample 30 wherein an aperture will be formed in the light shield 284 between the
7 light source 120 lamp 123 and sample 30 limiting surface reflection from the sample
8 surface 35 to the light detectors 80 and 3) the light shield 284 may provide filter 130
9 function, e.g., heat blocking, cutoff and bandpass, between the light source 120 lamp
10 123 and sample surface 35 limiting the possibility of heat or burn damage to the
11 sample 30.

12 An additional embodiment is seen in Fig. 8, 8A and 8B wherein at least one
13 light shield 284 is positioned by a bracket article 275 to separate the at least one light
14 source 120 and lamp 123 from the at least one light detector 80 as a sample 30 is
15 conveyed by a sample conveyor 295 under and past a light source 120 and lamp 123
16 toward and under a light detector 80. The light shield 284 may be a curtain 285 and
17 is depicted in Fig. 8 as a curtain 285 composed of at least one portions and as shown
18 in Fig. 8A of two portions or a plurality of portions, each suspended from a bracket
19 article 275. Where there are a plurality of curtain 285 portions, the respective curtain
20 285 portions will overlap and separate as the sample 30 passes.

21 In this embodiment, as shown in Fig. 8, the sample 30, for example an apple,
22 is conveyed by a packing/sorting conveyance system 295. A cycle will be repeated as
23 each sample 30 moves toward, into contact with, under and past the light shield 284.
24 The packing/sorting conveyance system 295 will have samples 30 sequentially
25 positioned on the conveyance system 295 such that the space between sample 30 is
26 minimal generally in relation to the size of the sample 30. As the sample 30 moves
27 toward, but is not in contact with, the light shield 284 the sample 30 will be
28 illuminated by the light source 120 while the light detector 80 will detect only
29 ambient light and will be shielded from the light source 120. As the sample 30
30

1 moves into contact with and under the light shield 284 the sample 30 will, while
2 continuing to be illuminated by the light source 120, be exposed to the light detector
3 80 which will detect spectrum from the sample 30. When the sample 30 moves past
4 the light shield 284 the light detector 80 will again be shielded from the light source
5 120 and will detect only ambient light. The light source 120 may, for example, be a
6 tungsten/halogen lamp or light transmitted by optics to illuminate the sample 30. The
7 light detector 80, for example a optic fiber detector, is positioned such that the sample
8 surface 35 will be proximal to the light detector 80 as the sample 30 contacts and
9 passes under the light shield 284. The light shield 284 may be composed of a flexible
10 or pliable sheet opaque to the spectra to which the light detector 80 is sensitive and
11 may be comprised, for example, of silicone rubber, Mylar, thermoplastics and other
12 materials. The light detector 80, light shield 284 and light source 120 will be
13 mechanically affixed by bracket articles 275 or other mounting apparatus or methods
14 readily recognized by those of ordinary skill in the art or measurement at
15 packing/sorting systems.

16 An alternative configuration of the embodiments of Fig. 7 and 8 will employ a
17 plurality of light sources 120 including, for example a light source 120 illuminating
18 the sample 30 from the top with a second light source 120 illuminating the sample 30
19 from the side or two light sources 120 illuminating the sample 30 from opposite sides
20 illustrating the multiple positions which may be employed for light sources 120. A
21 plurality of light detectors 80 will view the same or different sample surface 35
22 locations with each light detector 80 output 82 either sensed by a separate
23 spectrometer or combined to form a single output 82. Where a plurality of outputs 82
24 are received by a plurality of spectrometers 170 at least one spectrometer 170 will
25 have a neutral density filter installed to block some percentage, e.g. 50%, of the
26 output 82 from the light detector 80 with this spectrometer 170 to provide data from a
27 particular spectral range, e.g., approximately 700 to approximately 925 nm. A second
28 spectrometer will not use a filter and will saturate from approximately 700 to 925 nm
29 but will yield good signal to noise (S/N) data from approximately 500 to 699 nm and
30

1 approximately 926 to 1150 nm. Other outputs 82 to filtered input spectrometers 170
2 will permit the examination of specific spectral ranges. Additionally, this method
3 allows the use of the same exposure times on both, or a plurality of, spectrometers
4 170 making them easier to control in parallel. This is essentially the dual exposure
5 approach using filtered input 82 to the spectrometer 170 rather than different
6 exposure times. The blocking of light to one spectrometer 170 effects the same result
7 as using a shorter exposure time. The dual intensity approach proves problematic
8 because the high and low intensity spectra are not easily pasted or combined together
9 due to slope differences in the spectra, however the dual intensity approach may be
10 preferred for predicting certain parameters (e.g., firmness, density) with certain
11 sample types (e.g. stored fruit or oranges). While the dual exposure approach yields
12 excellent combined spectra, both approaches provide useable combined spectra,
13 which are necessary for firmness and other parameter prediction and also improved
14 Brix accuracy.

15 Typically, Partial Least Squares (PLS) regression analysis is used during
16 calibration to generate a regression vector that relates the VIS and NIR spectra to
17 brix, firmness, acidity, density, pH, color and external and internal defects and
18 disorders. This stored regression vector is referred to as a prediction or calibration
19 algorithm. Spectral pre-processing routines are performed on the data prior to
20 regression analysis to improve signal-to-noise (S/N), remove spectral effects that are
21 unrelated to the parameter of interest, e.g., baseline offsets and slope changes, and
22 "normalize" the data by attempting to mathematically correct for pathlength and
23 scattering errors. A pre-processing routine typically includes "binning", e.g.,
24 averaging 5-10 detector channels to improve S/N, boxcar or gaussian smoothing (to
25 improve S/N) and computation of a derivative. The 2nd derivative is most often
26 used, however, the 1st derivative can also be used and the use of the 4th derivative is
27 also a possibility. For firmness prediction, data is often used after binning,
28 smoothing and a baseline correction or normalization; where no derivative is used.
29 For Brix and other chemical properties, a 2nd-derivative transformation often is best.
30

1 Using a Principal Components Analysis (PCA) classification algorithm, soft
2 fruit and very firm fruit can be uniquely identified from moderately firm fruit. Also,
3 under-ripe and ripe fruit can be separated and spoiled, e.g., higher pH, or rotten fruit
4 can be identified for segregation. The NIR spectra of whole apples, and other fruit, in
5 the approximately 250-1150 nm region also show correlation with pH and total
6 acidity. The 250-699 nm wavelength region contains color information, e.g.,
7 xanthophylls, yellow pigments, absorb in the 250-499 nm region; anthocyanin, which
8 is a red pigment, has an absorption band spanning the 500-550 nm region, improves
9 classification or predictive performance, particularly for firmness. An example is the
10 prediction of how red a cherry is by measuring and applying or comparing the
11 anthocyanin absorption at or near 520 nm to the pertinent predictive or classification
12 algorithm. Under-ripe oranges, having a green color, can be predicted by
13 measurement of sample spectrum output 82 in the chlorophyll absorption region
14 (green pigments) at or near 680 nm and applying the measured output 82 spectrum to
15 the pertinent predictive algorithm. The spectrum output from the sample, in the 950-
16 1150 nm region has additional information about water, alcohols and acids, and
17 protein content. For example, sample water content relates to firmness in most fruit
18 with water loss occurring during storage. High pH fruit, often indicative of spoilage,
19 can also be uniquely identified in the presence of other apples using a classification
20 algorithm.

21 The present disclosure is a non-destructive method and apparatus for
22 measuring the spectrum of scattered and absorbed light, particularly within the NIR
23 range of 250-1150 nm, for the purpose of predicting, by use of the applicable
24 predictive algorithm, particular fruit characteristics including sugar content, firmness,
25 density, pH, total acidity, color and internal and external defects. These fruit
26 characteristics are key parameters for determining maturity, e.g., when to pick, when
27 to ship, when and how to store, and quality, e.g., sweetness/sourness ratio and
28 firmness or crispness for many fruits and vegetables. These characteristics are also
29 indicators of consumer taste preferences, expected shelf life, economic value and
30

1 other characteristics. Internal disorders can also be detected, e.g., for Tasmania
2 Jonagold apples, including disorders such as water core, core rot, internal
3 browning/breakdown, carbon dioxide damage, and, in some cases, insect
4 damage/infestation. The disclosure simultaneously utilizes 1): the visible absorption
5 region (about 250-699 nm) that contains information about pigments and chlorophyll,
6 2) the wavelength portion of the short-wavelength NIR that has the greatest
7 penetration depth in biological tissue, especially the tissue of fruits and vegetables
8 (700-925 nm), and 3) the region from 926-1150 nm, which contains information
9 about moisture content and other O-H components such as alcohols and organic acids
10 such as malic, citric, and tartaric acid.

11 Benchtop, handheld, portable and automated packing/sorting embodiments
12 are disclosed. The benchtop embodiment will generally be distinguished from the
13 high speed packing/sorting embodiment through the greater ease of examining the
14 sample 30 with more than one intensity light source 120, i.e., lamps 123 or light
15 sources 120 controlled with more than one voltage or power level or more than one
16 exposure time. A benchtop embodiment discussed herein utilizes a dual intensity
17 light source 120, e.g., by utilizing dual voltages or dual exposure times or other
18 methods of varying the intensity of the light source 120 used to illuminate the sample
19 30. Alternatively, the light detector 80 may be operated to provide at least one
20 exposure at one lamp 123 intensity and, for example, the light detector 80 may
21 provide dual or a plurality of exposures at 1 lamp intensity. The method of providing
22 dual or a plurality of exposures at one lamp intensity is accomplished as follows: the
23 light detector 80 exposure time is adjustable through basic computer software control.
24 In the computer program, two spectrum of different exposure times are collected for
25 each sample 30. The benchtop method may, as preferred by the operator, involve
26 direct physical contact between the sample surface 35 and the apparatus delivering
27 the light source 120, e.g., at least one light detector 80 may penetrate the sample
28 surface 35 into the sample interior. A high speed packing/sorting embodiment
29 generally will be limited in the delivery or the exposure of the light source 120,
30

1 relative to or at the sample surface 35, resulting from the limited time, usually a few
2 milliseconds, the sample 30 will be in range of the light source 120. Multiple passes
3 or arrangements of multiple light sources 120 and multiple light detectors 80,
4 including photodetectors 255 and other light detection devices, will permit, in the
5 highspeed packing/sorting embodiment, the exposure of the sample to multiple light
6 source 120 intensities. The handheld embodiment generally will allow sampling of a
7 limited number of items by orchard operators, i.e., in inspection of fruit samples on
8 the plant or tree, and from produce delivered for packing/sorting, to centralized
9 grocery distribution centers or individual grocery stores.

10 Obtaining data over the wavelength region of 250-1150 nm is only possible
11 using a multi intensity or multi exposure measurement, i.e., dual intensity or dual
12 exposure as in the preferred embodiment. While one spectrometer can be used to
13 cover the 500-1150 nm region, a second spectrometer is necessary to cover the 250-
14 499 nm region. The number of different light source intensity or exposures required
15 is dependent on the characteristics of the sample and of the detector 200. The
16 spectrum acquired at longer detector 200 exposure times or higher light source
17 intensity saturates the detector pixels, for some detectors, e.g., Sony ILX 511, or
18 Toshiba 1201, from ~700-925 nm, yet yields excellent S/N data from ~500-699 nm
19 and from ~926-1150 nm. The low intensity or shorter exposure time spectrum is
20 optimized to provide good S/N data from 700-925 nm. Accurate firmness predictions
21 of fresh and stored fruit requires the 700-925 nm region and the 500-699 nm, e.g.,
22 pigment and chlorophyll, plus the 926-1150 nm region. Addition of the 250-499 nm
23 region, e.g., yellow pigments known as xanthophylls which absorb light, will
24 improve prediction of firmness and other parameters such as Brix, acidity, pH, color
25 and internal and external defects. There is high correlation between the spectrum
26 output from the sample 30 in the 926-1150 nm region with water content. Stored
27 fruit appears to have higher relative water content than fresh fruit and less light
28 scattering. The chlorophyll and pigment of a sample 30 is predicted by correlation
29 with the sample spectrum output 82 in the 250-699 nm region, with this correlation
30

1 likely being the most important for prediction of firmness of fresh fruit, while the
2 longer wavelength water region may be more important for accurate firmness
3 measurement of stored fruit.

4 Just as in the longer NIR wavelength regions, the 700-925 nm region also
5 contains absorption bands from carbon-hydrogen, oxygen-hydrogen, and nitrogen-
6 hydrogen bonds, e.g., (CH, OH, NH). In the case where protein is key component of
7 interest, the 926-1150 nm region is of greatest interest. However, pre-sprout
8 condition in grain, for example, can be predicted by examination of the sample
9 output spectrum in the 500-699 nm region.

10 The preferred embodiment of the apparatus is composed of at least one light
11 source 120, a sample holder 5 including, for example a sorting/packing sample
12 conveyor 295 and other devices and methods of positioning a sample 30, with at least
13 one light detector 80, i.e. optical fiber light sensors in the preferred embodiment,
14 detecting the sample spectrum output 82 to be received by a spectrum measuring
15 instrument such as a spectrometer 170 with a detector 200, e.g., a CCD array, with
16 the signal thus detected to be computer processed, by a CPU 172 having memory,
17 and compared with a stored calibration algorithm, i.e., stored in CPU 172 memory,
18 producing a prediction of one or more characteristics of the sample. The at least one
19 light source 120 and at least one light detector 80 are positioned relative to the sample
20 surface 35 to permit detection of scattered and absorbed spectrum issuing from the
21 sample. Bracket fixtures 275, brackets and other recognized positioning and affixing
22 devices and methods will be employed to position light sources 120, light detectors
23 80 and sample holders 5. In the preferred embodiment the positioning of the light
24 source 120 and light sensor or light detector 80 will be such as to shield 84 the light
25 detector 80 from direct exposure to the light source 120 and will limit the light
26 detector 80 to detection or exposure of light transmitted from the light source 120
27 through the sample 30. The light source 120 may be fixed in a conical or other cup or
28 shielding container which will allow direct exposure of the light source 120 to the
29 sample surface while shielding the light source 120 from the light detector 80.
30

1 Alternatively, the light detector 80 may be fixed in a shielding container, e.g., a shield
2 84 or ambient shield 262, thus shielding the light detector 80 from the light source 80
3 and exposing the light detector 80 solely to the light spectrum transmitted through the
4 sample 30 from the light source 80 to the light detector 80. The spectrum detected by
5 the light detectors 80, i.e., the signal output 82, is directed, as input, to at least one
6 spectrometer 170 or other device sensitive to and having the capability of receiving
7 and measuring light spectrum. In the preferred embodiment two or more
8 spectrometers 170 are employed. One spectrometer 170 monitors the sample
9 channel, i.e., the light detector 80 output 82, and another spectrometer 170 monitors
10 the reference, i.e., light source 120 channel. If the lamp 123 is turned on and off
11 between measurements, ambient light correction can be done for both light detector
12 80 and light source 120 channel, e.g., spectrum collected with no light is subtracted
13 from spectrum collected when lights are on and stabilized. Alternatively, the light
14 source 120 can be left on and ambient light can be physically eliminated using a
15 shield 84 or ambient shield 262, such as a lid or cover or appropriate light-tight box.
16 The discussion of shielding of the light detector 80 composed of fiber optic fibers
17 applies as well to photodetectors 255 and the utilization of light sources other than
18 tungsten halogen lamps including for example light emitting diodes 257.

19 Another alternative with multiple sampling points and thus multiple light
20 detectors 80, as with fiber-optic sensors, is to converge all or some sampling points,
21 as depicted in Fig. 4, back to a single sample or light detector 80 channel
22 spectrometer 170, e.g., using a bifurcated, trifurcated or other multiple fiber-optic
23 spectrometer 170 input. Multiple or a plurality of sample points, i.e., light detectors
24 80, provides better coverage of a sample 30, e.g., sampling is more representative of
25 the sample 30 as a whole, or allows multiple points, e.g., on a conveyor belt full of
26 product, to be measured by a single spectrometer 170 thus providing an "average"
27 spectrum that is used to predict an average property such as Brix for all sample 30 or
28 light detector 80 channels.

29

30

1 In the preferred embodiment two or more spectrometers 170, or at least two
2 spectrometers 170 are used for reference and or measurement. A spectrometer 170
3 used in gathering data for this invention utilized gratings blazed at 750 nm to provide
4 coverage from 500-1150 nm. Additionally, spectrometers 170 operating in the 250-
5 499 nm wavelength region can be included to provide expanded coverage of the
6 visible region where xanthophylls, e.g., yellow pigments, absorb light. Information in
7 the output 82 spectrum detected from 1000-1100 nm also contains repeated
8 information, if a cutoff or long-pass filter is not used, from 500-550 nm, e.g.,
9 regarding Anthocyanin, which is a red pigment, has an absorption band spanning the
10 500-550 nm region, which improves classification or predictive performance,
11 particularly for firmness,

12 The spectrometers 170 used in the preferred embodiment have charge-coupled
13 device (CCD) array detectors 200 with 2048 pixels or channels, but other array
14 detectors 200, other light detectors 80, including other detector 200 sizes vis-a-vis
15 array size or other method of detector size characterization, may be used as would be
16 recognized by one of ordinary skill in the art. One of the two spectrometers 170
17 monitors the light source 120 intensity and wavelength output directly, providing a
18 light source reference signal 81 that corrects for ambient light and lamp, detector, and
19 electronics drift which are largely caused by temperature changes and lamp aging.
20 The other spectrometer(s) 170 receives the light detector 80 signal output 82 from
21 one or more light detectors 80 which are sensing light output from one or more
22 samples 30 and/or one or more locations on a sample 30, e.g., at multiple points over
23 a single sample 30, such as an apple, or at multiple points over a sample conveyor
24 295 belt of apples, grapes or cherries, or a different sample 30, e.g., a different lane
25 on a packing/sorting line, can be measured with each additional spectrometer 170.
26 Each light sensor, e.g., light detector 80(photodetector 255 or other light sensing
27 apparatus or method), in the preferred embodiment represents a separate sample 30 or
28 different location on the same sample 30 or group of samples 30. Spectra from all
29 spectrometers 170 are acquired, in the preferred embodiment, simultaneously.
30

1 Depending on the type of spectrometer, A/D conversion can occur in parallel or series
2 for each spectrometer (parallel preferred). The computer then processes the spectra
3 and produces an output. Current single CPU computers process spectra in series. A
4 dual CPU computer, two computers, or digital signal processing (DSP) hardware can
5 perform spectral processing and provide output in parallel.

6 In an alternative embodiment spectra from the wavelength region from about
7 250-1150 nm, the near-infrared spectra, is examined from samples 30, e.g., fruit
8 including apples. In this particular experiment, a reflectance fiber-optic probe was
9 used as the light detector 80. While the spectrophotometer 170 used to collect the
10 data, i.e., sense the spectrum output 82 from the light detector 80, was a DSquared
11 Development, LaGrande, Ore., Model DPA 20, one of ordinary skill in the art will
12 recognize that other spectrometers and spectrophotometers 170 may be used. The
13 spectrophotometer 170 referenced employed a five watt tungsten halogen light source
14 120, a fiber-optics light sensor to detect the spectrum or output 82 from the sample 30
15 and provide the light sensor signal input 82 to the spectrometer 170. Other lamps 123
16 or light sources 120 may be substituted as well as other light sensors or light detectors
17 80. The light detector signal input 82 to the spectrometer 170, in this embodiment, is
18 detected by a charge coupled device array detector 200. The output from the charge
19 coupled device array detector is processed as described above. Firmness and Brix
20 were measured using the standard destructive procedures of Magness-Taylor firmness
21 ("punch test") and refractometry, respectively. In this embodiment the NIR spectra is
22 detected by an array detector 200 which permits recording or detection of 1024 data
23 points. The 1024 data points are smoothed using a nine-point gaussian smooth,
24 followed by a 2nd-derivative transformation using a "gap" size of nine points. Partial
25 least squares (PLS) regression was used to relate the 2nd-derivative NIR spectra to
26 Brix and firmness. To ensure that false correlation was not occurring, the method of
27 leave-one-out cross-validation was used to generate standard errors of prediction. In
28 cross-validation, the prediction model is constructed using all but one sample; the
29 Brix and firmness of the sample left out is then predicted and the process repeated
30

1 until all samples have been predicted. The validated model can then be used to
2 nondestructively predict Brix and firmness in unknown whole fruit samples. This
3 information guides harvest decisions indicating time to harvest, which fruit is suitable
4 for cold storage, where the fruit is classified from acceptable to unacceptable
5 characteristics of quality or consumer taste, which fruit to be removed from the
6 sorting/packing operation as not meeting required characteristics, e.g., firmness, Brix,
7 color and other characteristics.

8 This disclosure of embodiments of an apparatus and method is directed to the
9 simultaneous measurement and use of more than one spectral region from a sample.
10 In this embodiment the use of the chlorophyll absorption region and the NIR region,
11 including the highly absorbing 950-1150 O-H region, is accomplished by exposing
12 the sample, e.g. apple, to more than one intensity source of light or by exposing the
13 light detector 80 at more than one exposure time, e.g., a dual intensity source of light
14 or at least two intensities of light, or by detecting light from a sample with more than
15 one light detector 80 such that each light detector 80 is sensitive to a different
16 spectrum, e.g., by filtering one or more light detectors 80 with filtering either between
17 the sample 30 and the light detector 80 or between the light detector 80 output 82 and
18 the spectrometer 170 input. Fig. 1 illustrates filtered light sources 120 allowing
19 exposure of the sample 30 to different light intensities. Fig. 2 illustrated the use of
20 more than one light detector 80 where filtering between the sample 30 and light
21 detector 80 allows detection of different spectral regions. Shown in Fig. 3A, where
22 the light source is a plurality of discrete wavelength LEDs 257, is an embodiment
23 wherein the sample is exposed to a plurality of light intensities. The intensity of the
24 light source 120 will be selected to provide light output to the light detector 80 which
25 will give optimal S/N data in the desired spectral region. In a first pass a light source,
26 e.g., a lower intensity light source, is used to illuminate the sample, e.g. apple, to
27 obtain data, with an acceptable S/N ratio, in the 700-925nm region. At higher (>925
28 nm) and lower (<700 nm) wavelengths, the spectrum is dominated by noise due to the
29 low light levels and is not useful. In a second pass a higher intensity light source is
30

1 selected to illuminate the sample, saturating the detector array at the 700-925nm
2 regions while obtaining data with an acceptable S/N ratio, in the red pigment region
3 of 500-600 nm, the chlorophyll region of 600-699nm and in the O-H region of 926-
4 1000nm. The data from each of the two passes comprises separate data inputs
5 delivered to an analog to digital converter for computer processing. Same
6 spectrometer and A/D for benchtop unit, where the two spectra are acquired
7 sequentially. For on-line, two spectrometers are used, each with its own A/D. In one
8 embodiment A/D cards external to the computer are utilized which are serial and are
9 provided by Ocean Optics. This process is provides for multiple channels into a data
10 analyzer for analysis by software. In this embodiment Ocean Optics drivers, hereafter
11 referred to as drivers, accept MS "C" or Visual Basic to 1) determine the spectrum
12 detected from the sample or 2) subject the data to the predictive algorithm and
13 produce the output. Display control computer programs or software periodically
14 requests drivers to deliver the spectrums to be combined. The digital combination
15 then produces, with standard display software, the output display representing the
16 entire spectrum ranges detected from the each sample. There may be, for each
17 sample, multiple spectrum data. For example the spectrum sampling protocol may
18 seek 50 spectrum samples during each of the multiple passes, e.g., 50 spectrum
19 samples during the pass subjecting the fruit sample to the lower intensity light source
20 and separately 50 spectrum samples during the pass subjecting the fruit sample to the
21 higher intensity light source. The total duration of each pass will be determined by
22 the speed of the sorting/packing line and may be limited to approximately 5ms per
23 sample. However, it will be recognized, for all embodiments and sample types, that
24 other sampling times and strategies will be within the realm of use for the invention
25 disclosed herein as different samples and different embodiments are employed.
26 Where the samples being processed, on a sorting/packing line, are apples, there is
27 expected to be little space between each successive apple. Spectrum obtained from
28 the space between apples and at the leading and trailing sides of the sample or apple
29 will be discarded. As the sample, i.e., apple or other fruit, moves under the light
30

1 detector 80, the spectrum data detected will be that exiting the sample 30
2 representative of the portion of the sample 30 constituting the path between the point
3 of exposure of the sample 30 with the light source 120 and the point of spectrum exit
4 for detection by the light detector 80. By mathematical inspection of each spectrum,
5 e.g., automated inspection via a computer, this method can determine whether light
6 detected by the light detector 80 is from an apple or the empty space between apples
7 in a sorting/packing line sample conveyor 295. This method can also detect the
8 leading and trailing edges of an apple as it passes by the light detector 80 having an
9 output 82 to a spectrometer 170. From this data, discrimination can occur to select
10 specific spectra samples which, for example, are expected to be from the midsection
11 of the sample or apple. Using mathematical inspection of each spectrum (on-line) to
12 determine if it is a good apple spectrum or a spectrum of the line material. The cycle
13 detected by the light detector 80 thus, for each sample 30 in the on the sample
14 conveyor 295 of a sorting/packing line, is composed of an initial segment where the
15 light detector 80 or pickup fiber is exposed to only ambient light with a light shield
16 284 between the light detector 80 and the light source 120. As the sample 30, e.g.,
17 apple, moves into contact with and under the light shield 284, which may for example
18 be a curtain 285, the leading edge or side of the apple will commence to be revealed
19 permitting the light detector 80 to detect spectrum output 82 from the apple.
20 Continued movement of the sample 30 under the light shield 284 exposes the light
21 detector 80 to spectrum output 82 from the sample 30 until the sample 30 moves to
22 the point where the trailing edge or side of the sample 30 is remaining exposed to the
23 light source 120. The sample 30 then moves past the light shield 284 and all light
24 from the light source 120 is blocked between the light detector 80 and the light source
25 120. Thus the initial spectra detected by the light detector 80 will be at the leading
26 edge or side of the sample 30 as it approaches the curtain 285. The intermediate
27 spectrum measurements, between the initial time at which the leading edge of the
28 sample 30 is exposed to the light source 120 and the time when the trailing edge or
29 side of the sample 30 is exposed to the light source 120, will include those where the
30

1 light detector 80 or light pickup is optimally positioned to detect spectra most
2 representative of the characteristics of the light spectra output 82 from the sample 30
3 as the light source 120 illuminates the sample 30, e.g., apple, other fruit or other O-H,
4 C-H or N-H materials. In the preferred embodiment, for ease of data processing, the
5 light detector 80 analog output 82 is converted to digital data by an A/D card.
6 Computer program or software tests the data for acceptance or discarding. The
7 criteria for acceptance of each spectrum sample 30 is a predetermined spectral feature
8 determined by the expected spectral output 82 of the sample 30, e.g., where the
9 sample 30 is an apple, i.e., the criteria will be to detect a spectrum from 250 to
10 1150nm falling within the spectra expected for an apple. The detection of the space
11 between apples, in the sorting/packing line, will be recognized as not apples. This
12 spectrum acquired for each sample 30 is the input to the predictive algorithms as
13 indicated by the flow diagram of Fig. 1C. Multiple spectrum, for example fifty
14 spectrum, are detected by the light detector 80 for each sample. The computer
15 program compares each detected discrete spectrum with an expected spectrum from
16 the particular sample, the spectrum not meeting the criteria are discarded, the retained
17 spectrum, e.g., 40 - 50 samples, are combined to provide the spectrum which
18 becomes the input for the predictive algorithm. Multiple spectra from the same apple
19 are averaged to provide a single average spectrum representing multiple points on the
20 apple. the apple may be spinning as it travels by the sensor, e.g., clockwise or counter
21 clockwise in relation to the direction of sorting line travel with better measurement
22 indicated with counterclockwise motion of the sample, thus giving even greater
23 coverage of its surface. Once the average absorbance spectrum for a sample is
24 calculated, the spectrum is multiplied by the regression vector (via a vector
25 multiplication dot product). The regression vector is obtained from previous
26 calibration efforts and is stored on the computer. There is a separate regression
27 vector for each parameter being predicted - e.g., firmness, Brix. The results of the
28 processing the spectrum output 82 by the predictive algorithms will determine the
29 predicted characteristics of the sample 30. The characteristics determined for each
30

1 discrete sample 30, e.g., apple or other fruit, will be used for decision making in
2 handling or disposition of the sample 30 including, for example, 1) in the
3 packing/sorting line different characteristics will be used for sorting and packing
4 decisions, e.g., by color, size, firmness, taste as predicted by acidity and Brix and 2)
5 characteristics indicating spoilage may trigger methods of elimination of the
6 particular sample 30 from the packing/sorting line.

7 Packing and sorting of apples will likely involve multiple packing/sorting
8 illumination or light source 120 and light detector 80s for each line. Where the
9 sample 30 is comprised of smaller fruit, e.g., cherries or grapes, there may be
10 multiple light sensors with single or multiple light to interrogate or examine and
11 gather data from a tray of such smaller fruit rather than on the basis of examination of
12 each discrete cherry or grape. For each sample 30, data is acquired, tested to
13 determine if the data corresponds to preset criteria with data selected which meets
14 preset criteria and discarded if it fails to meet preset criteria. Data received by light
15 sensors is then combined to compose the total spectrum sampled. The total spectrum
16 is then compared with the predictive algorithm and decisions are made regarding the
17 sample 30 including, for example, sorting/packing decisions. The results of the
18 comparison of the total spectrum with the predictive algorithm provides a number or
19 other output for end use including information for computer directed sorting
20 equipment.

21 Operation of the light source 120 is enables the rapid acquisition of
22 reproducible data with good S/N, even in the highly light scattering and absorbing
23 250-699 nm and the strongly absorbing >950 nm region. The lamp 123 in the
24 preferred embodiment is a 12-Volt, 75-Watt tungsten halogen lamp. However, other
25 light sources which may be used include but are not limited to light emitting diode,
26 laser diode, tunable diode laser, flash lamp and other such sources which will provide
27 equivalent light source and will be familiar to those practiced in the art. The lamp is
28 held at a resting voltage of 2-Volts. When a measurement is taken, the lamp is
29 ramped up to the desired voltage, a brief delay allows the lamp output 82 to stabilize,
30

1 then spectra are acquired. After data acquisition, the lamp is ramped down to the
2 resting voltage. This procedure extends lamp life and prevents burning the sample.
3 In high speed operations the lamp may always be lighted, e.g., on a high-speed
4 packing/sorting line or used on harvest equipment, and a light "chopper" or shutter or
5 other equivalent article or method could be utilized to deliver light to the passing
6 sample for a determined period of time. The operation of the light source is
7 important in extending lamp life, reducing operating expense and reducing disruption
8 of operations. The lamp 123 voltage is ramped up and down to preserve lamp 123
9 life and to lessen the likelihood of burning fruit. A standby voltage to keeps the lamp
10 123 filament warm. An ambient/room light background measurement is made to
11 correct for the dark spectrum, which may include ambient light. It is stored and
12 subtracted from the sample and reference (if applicable) so that there is no
13 contribution of ambient light to the sample spectrum, which would affect accuracy..
14 Dual intensity illumination is employed to: 1) improve data accuracy above 925 nm
15 and below 700 nm and 2) to normalize path length changes due to scattering. Dual
16 exposure time increases the likelihood of increased data quality with large and small
17 fruit. Utilization of more than one light detector 80, with each positioned at different
18 distances from the sample, will likewise increase the ability to obtain increased data
19 quality throughout each portion of the spectrum from approximately 250nm to 1150
20 nm.

21 Other steps in determining predictive algorithms included reference
22 determination of pH using electrode measurement and reference determination of
23 total acidity using end-point titration of extracted juice. Correlation between the NIR
24 spectra and the reference data (pH and total acidity) was conducted. Methods known
25 to those practiced in the art such as partial least squares (PLS) are used to determine
26 the correlation of the NIR spectrum with a chosen parameter such as pH.. Once
27 correlation is established, PLS is used to generate a regression vector from the
28 calibration samples. This regression vector is then used to predict sample properties
29 by taking the dot product of the sample spectrum and regression vector. NIR analysis
30

1 can be carried out directly on the juice yielding very high correlations with Brix, pH,
2 and total acidity. A commercially available "dip probe" is used that is a common
3 item available from optical fiber fabricators or from companies involved in process
4 analysis. In addition to the use of PLS for quantifying Brix, firmness, pH and acidity,
5 Principal Components Analysis (PCA) was performed on the NIR spectral data. PCA
6 differs from PLS in that no reference data is required. PCA allows classification of
7 firm vs. soft apples and low pH vs. high pH samples. This classification algorithm is
8 sufficient to achieve the goal of product segregation. Using PCA, poor quality fruit
9 can be removed from a batch and the highest quality fruit can be segregated into a
10 premium class. Poor quality fruit was observed to often have a higher pH level than
11 good quality fruit.

12 Fig. 4 illustrates an alternative embodiment of the disclosure and includes at
13 least one light source 120 transmitted by a transmitting article, for example a fiber
14 optic fiber or other equivalent article for transmitting light; a sample 30 having an
15 sample surface 35; input mechanism of positioning light from the at least one light
16 source 120 proximal the sample surface; at least one illumination detector; output
17 mechanism of positioning the at least one illumination detector proximal the sample
18 surface; the at least one light source 120 and the at least one illumination detector
19 may be positioned in relation to the surface or against the surface by a positioning
20 article provided, for example, by a positioning article spring biased against the
21 surface of the sample; the pressure against a sample surface, by an at least one light
22 source 120 or an at least one illumination detector, will be limited by surface
23 characteristics of the sample and/or the character of the measurement process, i.e.,
24 pressure may be reduced where a sample is subject to surface damage or where the
25 measurement process is in at high speed limiting the time permitted for each separate
26 sample contact. The illumination is transmitted to the surface, for example by fiber
27 optics or other equivalent manner; and at least one device or method of measuring the
28 illumination detected from the sample. The light source, for the disclosure herein
29 may be a broadband lamp, which for example, but without limitation, may be a
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1 tungsten halogen lamp or the equivalent, which may produce a spectrum within the
2 range 250-1150 nm and have a filament temperature of of 2500 to 3500 degrees
3 kelvin; other broadband spectrum lamps may be employed depending upon the
4 sample 30, characteristics to be predicted, and embodiment utilized; the at least one
5 device or method of measuring the illumination may be a spectrometer having at least
6 one input; the at least one spectrometer may include, for example, a 1024 linear array
7 detector with those of ordinary skill in the art recognizing that other such detectors
8 will provide equivalent detection; the at least one illumination detector may be a light
9 pickup fiber or other equivalent detector including for example a fiber optics light
10 pickup; the at least one illumination detector collects a spectrum which is received by
11 the at least one spectrometer input; the sample in this embodiment is from the
12 chemical group of CH, NH, OH or the physical characteristics of firmness, density,
13 color and internal and external defects. Additionally, the light source 120 may
14 comprises a plurality of illumination fibers. In this embodiment a plurality of
15 illumination fibers may be arrayed such that each of the plurality of illumination
16 fibers is equidistant from adjacent illumination fibers; the at least one illumination
17 detector may, in this embodiment, be positioned centrally in the array of illumination
18 fibers. In an embodiment of this disclosure, the plurality of illumination fibers may,
19 for example, be comprised of 32 illumination fibers and the light source 120 may be
20 provided, for example, by a 5w tungsten halogen lamp or other equivalent light
21 source or by a plurality of illumination sources provided for example by at least two
22 light sources such as, for example, at least two 50 Watt light sources. Illumination
23 sources may be composed, for example, of sources having a focusing ellipsoidal
24 reflector with cooling fan. In this embodiment the at least one illumination detector
25 may comprise a plurality of light detectors 80, which may for example, be arrayed
26 such that each illumination detector is equidistant from adjoining light detectors 80;
27 where at least two light sources are positioned are employed, they may for example
28 be positioned 45 degrees relative to the illumination detectors. in the array of
29 illumination fibers. In an additional embodiment of this disclosure, a plurality of
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1 light detectors 80 may be comprised of twenty-two illumination detectors. An
2 embodiment of the disclosure may be comprised of at least one light source 120
3 composed of a 5 w tungsten halogen lamp; the at least one illumination detector is a
4 single detection fiber; the light source 120 is positioned against the sample 30 degrees
5 distal to the detection fiber. If the measurement of the sample surface is made in a
6 non-contacting manner, an alternative embodiment may include a polarization filter
7 between the light source 120 and the sample, provided, for example by a linear
8 polarization filter or an equivalent as understood by one of ordinary skill in the art; a
9 matching polarization filter is positioned between the at least one illumination
10 detector and the sample, which may be provided, for example by a linear polarization
11 filter rotated 90 degrees in relation to the polarization filter between the light source
12 120 and the sample.

13 The method described above, which uses wavelengths of both visible
14 radiation (250-699 nm) specifically chosen to include the absorption band for yellow
15 color pigments (250-499nm), red color pigments (500-600 nm) and green pigments
16 or chlorophyll (601-699 nm), as well as NIR (700-1150 nm) radiation to correlate
17 with Brix, firmness, pH, acidity, density, color and internal and external defects can
18 be carried out using a variety of apparatuses.

19 While a preferred embodiment of the present disclosure has been
20 shown and described, it will be apparent to those skilled in the art that many changes
21 and modifications may be made without departing from the disclosure in its broader
22 aspects. The appended claims are therefore intended to cover all such changes and
23 modifications as fall within the true spirit and scope of the disclosure.

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1 ~~NEW MATTER FOLLOWS FOR CH COPENING from the nonprovisional~~
2 ~~parent application 09/524,329 entitled AN APPARATUS AND METHOD FOR~~
3 ~~MEASURING AND CORRELATING CHARACTERISTICS OF FRUIT WITH~~
4 ~~VISIBLE/NEAR INFRA-RED SPECTRUM to Ozanich as filed March 13, 2000.~~

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7 ADDITIONAL BRIEF DESCRIPTION OF THE DRAWINGS

8 Fig 9 is an elevation depicting an additional embodiment of the invention
9 demonstrating at least one light detector 80 having an output 82 to a spectrometer 170
10 having a detector 200. A collimating lens 78 is intermediate the at least one
11 detector 80 and a sample 30. The detector 80 positioned to detect light from the
12 sample 30. Light source 120 lamps 123, a case 250 intermediate the light source 120
13 lamp 123 and a sample 30 conveyed by sample conveyor 295. An aperture 310
14 allows illumination of the sample 30 by the at light source 120 lamp 123. A least
15 light shutter 300 intermediate the light source 120 lamp 123 and aperture 310. The
16 light shutter 300 operable by shutter operating means. The shutter control means 305
17 receiving control signals from a CPU 172 having shutter operating control output
18 307. A reference light transmitting means 81 including fiber-optics receiving
19 reference light output from the light source 120 lamp 123. A reference light shutter
20 301 intermediate the light source 120 lamp 123 and the reference light transmitting
21 means 81. The reference light shutter 301 operable by shutter control means 305.
22 The reference light shutter 301 shutter control means 305 receiving control signals
23 from a CPU 172 having a shutter operating control output 307. The reference light
24 transmitting means 81 providing an input to the spectrometer 170. The CPU 172
25 providing lamp power output 125 to the light source 120 lamp 123. The spectrometer
26 170, receiving input from reference light transmitting means 81 having output 82
27 received as in input to the CPU 172. The spectrometer output 82 capable of A/D
28 conversion to form input to the CPU 172. The spectrometer 170, receiving input
29 from detector output 82 received as in input to the CPU 172. Mounting means
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1 indicated as described in other figures to light sources 120 lamps 123, detectors 80,
2 shutters 300, shutter control means 305, reference light transmitting means 81 and
3 case 250. Encoder/pulse generator 330 input to CPU 172 providing sample conveyor
4 295 movement data. Computer program to operate CPU 172 in data collection and
5 control functions.

6 Fig. 10 illustrates using spectroscopic sensors for measuring fruits and vegetables
7 while in motion on a sample conveyor 295. Shown is a sample 30 with proximity sensing
8 means 340. Demonstrated is the sample conveyor 295, a case 250, collimating lens 78.

9 Fig. 10A is a section from Fig. 10 illustrating the proximity sensing means 340 in
10 the form of reflectance means.

11 Fig. 11 illustrates the manner of taking a reference measurement of the light source
12 120 lamp(s) 123 where intensity vs. wavelength output can also be obtained using reflecting
13 means 360. Reflecting means 360 may be inserted via an aperture 310, for example in a case
14 250, when a reference measurement is to be made as dictated by reflecting control means
15 308 as an output from a CPU 172. The CPU 172, via means, will detect the presence or
16 absence of a sample 30 and, when a sample 30 is absent for "n" time increments or sample
17 conveyor 295 movements will provide a reflecting control means 308 control signal to
18 reflecting position means 306, e.g., linear actuator or rotary solenoid operated by
19 means, e.g., mechanical driven by electrical, pneumatic, hydraulic or other power
20 means.

21 Fig. 12 and 13 illustrate the mechanical insertion of reference means 430 in or near
22 the location where actual sample 30 is normally measured. Insertion is by insertion means
23 including but not limited to an actuator system 400.

24 Fig. 14 and 14A illustrate a means of reducing the width of apparatus structure by
25 mounting light source 120 lamps 123 distal from a sample 30 with spectrum from the sample
26 30 directed by reflecting means 360 and lens 78 or reference light transmission means
27 320 with spectra received via apertures 310.

28 Fig. 15 and 15A illustrates spectra detection from sample 30 other than discrete
29 increments, such as apples, including, for example potato chips, where light source 120
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1 lamps 123 illuminate the sample(s) 30 with detectors 80 receiving input with light detector
2 output 82 conveyed as input to spectrometers 170 detectors 200. In this illustration a lens
3 130 is depicted between the sample 30 and the detector 80. Illustrations 15 and 15A depict
4 in detail, with filter 130 and mounting means, a single detector 80.
5 A CPU 172, controlled by computer program, is not depicted in Fig. 10, 10A, 11, 12,
6 13, 14, 14A, 15 or 15A as a person of ordinary skill will appreciate such structure from
7 viewing other drawings presented herein.

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11 **ADDITIONAL DETAILED DESCRIPTION**

12 **Overview of calibration of visible/NIR sensors:**

13 Required calibration was addressed in the Parent Application 09/524,329, in
14 paragraphs, identified by page/line by pn/ln, as follows: 1/18; 3/17, 22, 28; 4/2; 8/8;
15 9/4; 9/14; 12/16; 16/8; 22/5; 31/21; 33/19; 39/10; 43/4; 47/1; 52/13 etc. Calibration
16 of spectroscopic maturity and quality sensors involves building algorithms that relate
17 the visible and near infrared spectrum of an individual fruit or vegetable to one or
18 more of the following: Brix (including, but not limited to sugar content, or sweetness,
19 or soluble solids content); acidity (including but not limited to total acidity, or
20 sourness, or malic acid content or citric acid content or tartaric acid content); pH;
21 firmness (including but not limited to crispness or hardness); internal disorders or
22 defects including but not limited to watercore, browning, core rot, insect infestation.
23 Furthermore, the individual property data collected above can be combined as
24 follows: using the ratio of the sugar content to acid content to better predict eating
25 quality, taste, sweet/sour ratio; using the combined data from two or more of the
26 following: sugar content, acid content, pH, firmness, color, external and internal
27 disorders to better predict eating quality.

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1 **Integrating visible/NIR sensors with packing, sorting and conveyance**
2 **systems and synchronizing data acquisition with product location/position to**
3 **optimize collection of sample data, and reference and standardization data.**

4 Sensing sample data including the presence or absence of a sample was
5 addressed in the parent in paragraphs, identified by page/line by pn/ln, as follows:
6 20/20; 36/8 etc. Using spectroscopic sensors for measuring fruits and vegetables
7 while in motion on a sample conveyor 295 system in sorting and packing warehouses
8 is illustrated in Fig. 10 and Fig. 10A and is done as follows: The presence or absence
9 of a sample 30 and the position/location of the sample 30 relative to the point of
10 spectrum measurement is determined using one or more of the following means: 1)
11 sample 30 position determination means and or sample conveyor 295 position
12 determination means, provided for example by an encoder or pulse generator 330, as
13 seen in Fig. 9, integral to the sample conveyor 295 and detecting sample conveyor
14 295 movement, provides one or more electronic or digital signals to a CPU 172
15 which initiates, by computer program control, control signals to initiate and stop
16 acquisition of spectra, 2) the spectrum itself is automatically inspected using
17 computer programs or programmed hardware, e.g., digital signal processors, to
18 determine if the sample 30 being measured is at the optimal location(s) for spectrum
19 measurement, 3) a proximity sensing means 340, including proximity sensors of, but
20 not limited to, magnetic, inductance, optical, mechanical sensors; and also known as
21 object presence sensors, such as thru-beam or reflectance sensors 341, is used to
22 provide information about the position, i.e., orientation or location of the product on
23 the packing or sorting line relative to the NIR sensor, e.g., light detector 80, and/or
24 size of the sample 30, such proximity sensing means 340 and their use being of
25 common knowledge to those practiced in the art of industrial processing object
26 presence sensing. The proximity sensing means 340 can be placed 1, 2, 3 or ...n
27 units of length, e.g., cups or pockets or conveyor belt length, before the NIR sensor,
28 e.g., detector 80, to indicate if 1, 2, or 3 or...n more empty spaces, e.g., cups or
29 pockets or a defined and known length of conveyor belt, are present in sequence, thus
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1 allowing a greater amount of time for performing dark spectra and/or reference
2 spectra and/or standard/calibration samples. Using one or more of the above
3 methods, the presence or absence of sample(s) 30 is determined over a defined length
4 of the particular sample conveyor 295 system. If sample(s) 30 is present, multiple
5 visible and near-infrared spectra are acquired as the sample 30 passes by the light
6 source 120 lamp(s) 123 providing light detector output 82 and spectrometer(s) 170
7 detector 200 input; such light collection may be achieved using a collimating lens 78
8 and or other light transmission means including for example fiber-optics to transfer
9 the light that has interacted with the sample 30 to the spectrometer(s) 170 detectors
10 200. If no sample 30 is present, other reference measurements are made to improve
11 stability and accuracy such as previously mentioned dark spectra, reference spectra
12 (lamp intensity and color output), and standard/calibration samples, which may be
13 optical filters or polymers or organic material with known and repeatable spectral
14 characteristics. Measurements that are made when no sample is present include, but
15 are not limited to 1) measuring a reference spectrum (intensity vs. wavelength) of the
16 light source(s), 2) measuring the dark current (no light conditions) of one or more
17 spectrometer(s) 170 detector(s) 200, including but not limited to the sample
18 spectrometer(s) 170 and the reference spectrometer(s) 170, and 3) standard or
19 calibration samples or filters 130 or material.

20 Obtaining a spectrum of the lamp(s) for determining reference light
21 output and obtaining baseline dark current spectra from detector(s). Both
22 reference and dark spectra are used with sample spectrum to calculate the
23 product's absorbance spectrum.

24 Reference to reference, baseline and dark spectra was addressed in the parent
25 in paragraphs, identified by page/line by pn/ln, as follows: 12/18; 39/10; 52/14 etc.
26 The reference measurements to account for changes in light source intensity or color
27 output can be obtained using a reference light transmission means 320, e.g., a fiber-
28 optic bundle which may be furcated, a light pipe or other means of transmitting light,
29 with a common end 322 providing input to a reference spectrometer 170, and, where
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1 furcated, one or more branched ends 81, each of which is mounted by means to allow
2 only light from the light source 120 lamp(s) 123 to enter the reference light
3 transmission means 320. A light shutter 300 is placed between each light source 120
4 lamp 123 and each reference light transmission means 320. The at least one light
5 shutter 300 can be opened and closed separately by shutter control means 305
6 including, for example, driven by a linear actuator or rotary solenoid or other
7 mechanical or pneumatic device, or all at once.

8 Each light source 120 lamp 123 in the system can be measured separately to
9 determine if it is faulty or if it will soon need replacement based on a stored intensity
10 vs. wavelength spectrum profile. The combined intensities from the reference light
11 transmission means 320 is used as the reference spectrum for purposes of calculating
12 an absorbance (or $\log 1/R$) spectrum, which is linear with concentration (e.g., percent
13 Brix or acidity or pounds of firmness, etc.).

14 Closing all of the light shutters 330 of the reference light transmission means 320
15 allow a dark current (no light condition) measurement of the spectrometer 170 detector(s)
16 200. The dark current is largely affected by temperature and must be periodically measured
17 and its intensity value at each wavelength (or detector) pixel subtracted from the reference
18 spectrum obtained with the shutters 330 open.

19 The sample spectrometer's 170 detector 200 dark current must also be periodically
20 measured by closing light shutters 330 that are placed between the light source and the
21 sample 30, or between the sample 30 and the sample spectrometer light collection fiber, seen
22 here as detector 80 and detector output 82, or between the light collection fiber and the
23 spectrometer 170. Similarly to the reference measurement, the dark current of the sample
24 spectrometer 170 must be subtracted from the sample spectrum obtained with the shutters
25 330 open. It will be appreciated that reference measurement must be made with respect to
26 the spectrometer 170 used for light source 120 lamp 123 measurement as well as for the
27 spectrometers 170 used to acquire detector 80 spectrum output 82 as processed in the
28 computer program controlled CPU 172 in association with algorithms for the
29 characterization of samples 30.

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